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Improvement of engineer-to-order process in mechanical engineering

Thesis submitted for examination for the degree of Master of Science in Technology.

Espoo 8.4.2019
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Diplomityön tiivistelmä

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Työn nimi Tilausohjautuvan mekaniikkasuunnittelun prosessin kehittäminen

Maisteriohjelma Konetekniikka **Koodi** ENG25

Työn valvoja Professori Petri Kuosmanen

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Päivämäärä 08.04.2019 **Sivumäärä** 57 + 1 **Kieli** Englanti

Tiivistelmä

Asiakkaat vaativat yhä enemmän poikkeavia sovelluksia tuotteisiin, mihin yritykset vastaavat tilausohjautuvalla suunnittelulla (engineer-to-order, ETO), joka mahdollistaa asiakasräätälöityjen tuotteiden valmistamisen. ETO-systeemeissä suunnittelutehtävät ovat ratkaisevassa osassa, ja ETO-prosesseissa on useita haasteita, jotka johtuvat menetelmään liittyvästä epävarmuudesta. ETO-prosessien hallinta on kuitenkin usein puutteellista. Osaamisintensiivisten (knowledge-intensive) prosessien, kuten ETO-prosessien, kuvaaminen on yleensä haastavaa. Kohdeyrityksen tilausohjautuvassa mekaniikkasuunnittelussa ei oltu toteutettu jatkuvaa parantamista, ja lisäksi pidettiin riskinä sitä, että mekaniikkasuunnittelu olisi koko ETO-prosessin pullonkaula. Työn tavoitteena oli kuvata ETO-mekaniikkasuunnittelun nykytilanne yrityksessä ja määritellä kehityskohteet analyysin perusteella.

Prosessia tutkittiin työpajan, haastattelujen ja havainnoinnin kautta. Työpaja ja haastattelut eivät tuottaneet tarpeeksi yksityiskohtaisia tuloksia, sillä menetelmät eivät kyenneet muuttamaan työntekijöiden ennakkoasenteita ja huolestuneisuutta prosessikehitystä kohtaan. Osallistavaa havainnointitutkimusta hyödynnettiin omaksumalla Gemba-metodologian perusperiaatteita, jolloin onnistuttiin parantamaan työntekijöiden luottamusta ja mielenkiintoa kehityksen suhteen. Sen pohjalta oli mahdollista laatia tarkka kuvaus prosessista ja suorittaa analyysi kunkin prosessiin kuuluvan tehtävän hyödyllisyydestä ja tarpeellisuudesta. Lisäksi tehtiin työaika-analyysi, jonka tarkoituksena oli toimia pohjana tehokkuusmittareille. Analyysiä ei kuitenkaan pystytty suorittamaan loppuun, sillä löydökset osoittivat, että dataa ei ole kirjattu riittävällä tarkkuudella, eikä sitä täten pystytty hyödyntämään.

Työn löydökset olivat yhdenmukaiset kirjallisuudessa esitettyjen ETO-systeemeille tyypillisten ongelmien kanssa. Suositukset kohdeyritykselle liittyivät osaamisen jakamiseen, tehtävien standardoimiseen, automaatioon, sekä tehtävien siirtämiseen muihin prosesseihin ja toimintoihin. Lisäksi työssä tuotiin esille osaamisintensiivisten prosessien kuvaamiseen liittyvät haasteet, ja havaittiin, että havainnointitutkimus oli sopivin menetelmä työntekijöiden osallistamiseen ja prosessien kuvaamiseen.

Avainsanat engineer-to-order, ETO, prosessien kehittäminen, prosessi, mekaniikkasuunnittelu

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Abstract of master's thesis

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Title of thesis Improvement of engineer-to-order process in mechanical engineering	
Master programme Mechanical Engineering	**Code** ENG25
Thesis supervisor Professor Petri Kuosmanen	
Thesis advisor(s) M.Sc. (Tech.) Jarkko Mattila, D.Sc. (Tech.) Raine Viitala	
Date 08.04.2019 **Number of pages** 57 + 1	**Language** English

Abstract

Many companies respond to increasingly varying and demanding customer requirements with engineer-to-order (ETO) production system that enables the production of customer-specific solutions. The design activities in ETO are crucial, and ETO processes struggle with many challenges due to uncertainty. Yet, they are often not managed properly. Describing and analyzing knowledge-intensive processes, such as ETO processes, is often found difficult. The case company mechanical order-specific engineering (OSE) process was lacking continuous improvement and posed a risk of being a bottleneck within the overall ETO process. Therefore, the objective of the study was to describe the current situation in the mechanical OSE process in the case company and define improvement targets based on the analysis.

The process was examined using a workshop, interviews and observation. The workshop and interviews did not result in sufficient level of detail to describe the process, because the methods were not able to overrule the prejudice and concerns of the employees towards process improvement. Through participant observation inspired by the Gemba methodology, the trust and enthusiasm of the employees was increased, and the current state could be understood and described. It enabled to analyze the activities and their value. In addition, a work time analysis was applied in order to define a performance metrics system for the mechanical ETO process. However, the key finding of the data analysis was that the data is not recorded according to instructions and the amount of data was thus insufficient for further analysis.

The findings of the study were in accordance with the characteristics of ETO systems presented in literature. The recommendations for the case company concerned knowledge sharing, standardization of activities, automatization, improving upstream functions and transferring tasks to other processes. In addition, the study demonstrated the challenges in describing knowledge-intensive processes, and it was found that the participant observation was the most applicable method in employee engagement and in process discovery.

Keywords engineer-to-order, ETO, process, process improvement, mechanical engineering

Acknowledgements

This thesis was conducted for ABB Oy Drives. I would like to express my gratitude of being part of the company where one will receive assistance and support, no matter what. I am especially thankful for M.Sc. Jarkko Mattila for giving me the opportunity to learn with a challenging topic, and not getting bored of me playing hard to get. Moreover, I want to thank Jarkko and M.Sc. Tommi Tuulenmäki for letting me utilize their vast amount of expertise, providing me guidance and encouragement, and helping me out through the challenges encountered during the thesis. I also want to acknowledge Prof. Petri Kuosmanen and D.Sc. Raine Viitala from Aalto University Department of Mechanical Engineering for great advising.

My friend and colleague Aukusti Kankaanpää deserves my deepest gratitude for sharing the tears and joys during the thesis and his position as an indispensable peer support. My parents have played an important role not only for encouraging me during the thesis but also for believing in me throughout my studies. I am also grateful to Helga and Topi for providing me irrecoverable mental care. Lastly, I would like to thank everyone who reassured that “it’s going to be fine” and to acknowledge them for being absolutely correct.

Espoo 08.04.2019

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Abbreviations

BOM	Bill of materials
BPI	Business process improvement
BPR	Business process re-engineering
CAD	Computer-aided design
CTO	Configure-to-order
ERP	Enterprise resource planning
ETO	Engineer-to-order
DMAIC	Define, measure, analyze, improve, control
KIBP	Knowledge-intensive business process
OSE	Order-specific engineering
PDCA	Plan, do, check, act
SIPOC	Suppliers, inputs, process, outputs, customers
TOC	Theory of constraints

1 Introduction

In order to be competitive, companies need to fulfill increasingly varying and demanding customer requirements. Customers desire high-quality products with rapid delivery times and at reasonable prices. In addition, today they expect to have custom-made products. Engineer-to-order (ETO) is a strategy that provides customized products to customers. In ETO production, the process is highly customer driven which means that neither the final design or the production is started before the order is confirmed by the customer. (Haug et al. 2013)

There are various ETO production systems depending on the company and the products. ETO design processes can be the responsibility of the product development or be carried out by an independent order-specific engineering (OSE) department (Schönsleben et al. 2017; Willner et al. 2014). The complexity and the degree of customization can be different as well as the design and complexity of the production processes. Despite the differences, all ETO systems have the same characteristics and issues. (Muntslag 1993, p. 3-4)

ETO processes deal with many challenges which arise out of uncertainty. Before the order is confirmed, it is difficult to forecast the needed material and work resources both in production and in engineering to complete the work. False forecasts easily cause haste into design processes, overtime and delays in projects. (Bertrand & Muntslag 1993; Little et al. 2000; McGovern et al. 1999) The time pressure in engineering affects to the quality of the design, and thus, the quality in production. This again leads to delays and additional costs caused by the rework to correct the defects both in engineering and in production. (Ullman, 2010, pp. 3-8) In addition, customer changes after confirmation are a common issue causing uncertainty in the ETO system, as the customers are not always sure about their requirements in the beginning. (Bertrand & Muntslag 1993; Little et al. 2000; McGovern et al. 1999)

Companies should continuously aim to improve their processes and operations to meet the customer requirements. Otherwise they will quickly lose their customers to the competitors. (Andersen 2007, p. 3) In ETO companies, the customer requirements are even more difficult to fulfil because of the challenges caused by uncertainty. It is vital that effort is continuously put into the improvement of the processes.

Little et al. (2000) state that the design activity in ETO processes is critical and, yet, most often, not managed properly which causes late deliveries to customer. The present study focuses on improving the processes in mechanical engineering of customer-specified products at a case company. The processes of mechanical engineering should enable the production of high-quality products quickly and on time. The main objective is to study the current state of the process, and then provide improvement targets for the case company. Even though the results only concern this specific case, the methods for finding improvement targets can be widely applied in other situations, as well.

1.1 Research problem

The mechanical OSE team at the case company has not been through any major improvement actions for a while. The processes have not been studied neither have their performance been evaluated. Therefore, no specific problems have emerged, but the management suspects that the process could be operating more efficiently.

While the organization has applied continuous improvement in its operations, the mechanical OSE team has been left behind. Changes have been made in the organization and new products have been manufactured for several years, but the processes date back to the time when the old product family was still manufactured. Therefore, it is justified that the processes are studied in case there is something that could be done more efficiently in the present situation.

A part of the mechanical OSE team, called mechanical inspection, plays an important role in the company. The main reason the mechanical inspection exists is that it ensures smooth operation for production with minimal design issues. The product development releases products that are not finalized, because there is a high time pressure to offer new products to customers. The mechanical inspection team corrects the mistakes due to faulty product configuration and reports them so that the same mistakes do not emerge again. Therefore, the mechanical inspection team is essential in the whole business context as it ensures that the company can provide high-quality products without delays to the customers.

The resources of mechanical inspection have been reduced significantly. Simultaneously, another part of the team, mechanical design, has increased its capacity. There is a concern that the mechanical inspection represents the bottleneck function in the ETO process, and in high loads, work in process increases due to capacity overload in mechanical inspection, and the projects do not proceed due to the bottleneck.

Therefore, because of the importance of the mechanical inspection and the changes in the capacity, it is vital to investigate if the workload of the mechanical inspection could be diminished by eliminating non-value adding process steps, by transferring some tasks to the other employees in the ETO team, or by applying automatization. The challenge is that it is not clear how the inspection process currently operates in detailed level, and processes cannot be improved before they are understood.

1.2 Research objectives

The aim of the present study is to identify improvement targets in the mechanical engineering processes at the case company. The purpose is to first study the process to get a general overview of the processes. Then, using different methods, the present study seeks for the weaknesses and non-value adding activities in the process. Thus, the research questions are:

1. What is the current mechanical OSE process at the case company?
2. How can the workload be reduced or balanced within the mechanical OSE team?

Sub-research questions help finding proper answers to main research questions. They focus on the elimination of unnecessary parts of the job, the modification of the way the job is executed and rearranging of tasks to different resources. The sub-research questions are:

3. Why is a process step done?
4. Is a process step necessary?
5. How is a process step done? Why is it done in that particular way?
6. When is a process step done? Why is it done at that particular time?

To reach the objective and to answer to research questions, a suitable research method should be applied. Another objective in this thesis work is to evaluate how the chosen research methods are applicable in this type of situation. Then, after the issues are identified, they are analyzed, and solutions for the found issues are proposed.

1.3 Research scope

There are multiple improvement approaches developed for business processes, as discussed later in Chapter 2.2, and their level of improvement differs. In the present study, the aim is to describe the current state of the process, and therefore it is more applicable to focus on the methods that are mainly based on current state analysis, rather than radical methods aiming to create completely new processes from scratch.

The implementation is left out of the study and the development targets formulated in the study are given as suggestions. The scope is limited only on the specific team and its actions. The collaboration with other teams is within the scope, if it is seen beneficial to the mechanical engineering processes. The study does not cover the organizational and product structures or tools and systems.

1.4 Research methods

The research was conducted using a single case study. It was formalized as a mixed methods research that combines the qualitative and quantitative approaches. (Saunders et al. 2015, p. 169) Whereas quantitative research utilizes numerical data, the qualitative research aims to build data based on perspective of individuals (Bell & Waters 2014). In order to succeed in implementing changes, involving the stakeholders in improvement activities is important (Toikko & Rantanen 2009; Vandeveen & Menefee 2006, p. 206).

To provide a platform for team discussion and to involve the team members in the development, *a Kaizen workshop* was organized (Medinilla 2014; Melnyk et al. 1998). Individual *interviews* were conducted to gather more information about the processes in a context where the focus is on the perspective and experiences of individuals. In addition, *observation* was used to obtain profound knowledge about the process activities.

As Kaizen workshop, interviews and observation are classified as qualitative research methods, there is a need for a quantitative method to fulfill the requirements of mixed-methods research. The quantitative method used was *a work time analysis*. Its purpose is to give a data-based approach to problem identifying.

2 State-of-the-art review

This chapter covers the theoretical background for process improvement. First, process is briefly defined as a concept. Then, several process improvement approaches are introduced, and a general framework for process improvement is presented utilizing the approaches. Lastly, the ETO is shortly described as a concept, and the OSE function in the case company is presented, which gives an overview of the initial situation for the research.

2.1 Processes and their complexity

Process can be defined as a set of activities, also known as process steps, that are initiated by an event and produce a result. The initiating events are called as inputs, that come from the process suppliers, and the process ends up with outputs that are delivered to process customers. (Harmon 2014, pp. 185-186; Krajewski et al. 2016, p. 23) Process customers and suppliers can be either external or internal. External customers are, for example, the end-customer of a product or a service. Internal customer can be defined as a following process within the same organization, and internal supplier, respectively, a preceding process within the organization that supplies relevant information or semi-finished goods into the next process. (Krajewski et al. 2016, p. 25)

A process involves the employees carrying out the process, the information being exchanged and the information systems. (Dumas et al. 2013, p. 256) Business process deals with the execution of business tasks and coordinates their timeliness, task distribution, and methods and tools used to accomplish tasks. (Becker & Khan 2003, p. 4)

Processes can be simple or highly complex. Simple processes construct of simple, repetitive activities and tasks. Simple processes can usually be automated, whereas for extremely complex processes it is impossible. (Harmon 2014, pp. 189-191) Complex processes require knowledge to execute creative and unpredictable activities, hence they are often defined as *knowledge-intensive business processes* (KIBP). ETO processes are an example of KIBP, as they usually are based on tacit knowledge, involve many stakeholders, cannot be fully automatized, contain many iterations, and are strongly affected by external events, for example customer changes. (Unger et al. 2015; Willner et al. 2014)

The more complex the process is, the more difficult it is to define and analyze. Complex processes require a high level of creativity during the activities as exceptions emerge often. The process steps cannot be too strictly defined because in many occasions different approaches to fulfill the tasks are needed. (Harmon 2014, pp. 189-191)

2.2 Process improvement

Juran et al. (1999) state that improvement means “the organized creation of beneficial change”. The aim of process improvement is to achieve better customer satisfaction and financial results by different means (Andersson et al. 2006). Deming’s (1986) plan-do-check-act (PDCA) cycle has been the pioneer in the process improvement approaches. Afterwards, multiple more elaborate approaches have been developed.

Table 1 describes the general idea that all the approaches have in common. First, the process must be selected, then understood and finally it can be analyzed and improved through data collection and measurements. After the implementation, the process should be controlled in order to keep changes and measure the benefits. (Krajewski et al. 2016, p. 83)

Table 1. Process improvement approaches.

	Identification	Discovery	Analysis	Redesign	Implementation & control
PDCA (Deming 1986)	Plan	Do		Check	Act
DMAIC (e.g., Antony 2006; Shankar 2009)	Define	Measure	Analyze	Improve	Control
BPI (Dumas et al. 2013)	Process identification	Process discovery	Process analysis	Process redesign	Process implementation Process controlling
Lean (e.g., Anderson et al. 2006; Hines et al. 2010)	Identify value	Identify value stream		Create flow Create pull	Strive for perfection
Theory of Constraints (e.g., Nave 2002)	Identify constraint	Exploit constraint		Subordinate processes	Elevate constraint Repeat cycle
MIPI (Adesola & Baines 2005)	Understand business needs	Understand the process	Model & analyze process	Redesign process	Implement new process Asses new process & methodology Review process
SUPER (Lee & Chuah 2001)	Select the process	Understand the process	Process measurement	Process improvement	Review the improved process
BPS/I (Paper 1998)	Process selection	Process mapping		Process improvement	Process verification Process implementation
BPR (Davenport 1990)	Develop the business vision and process objectives Identify the process to be redesigned	Understand and measure the existing processes	Identify information technology levers	Design and build a prototype of the new process	
BPR (Shin & Jemella 2002)	Energize	Focus		Invent	Launch
BPI (Harrington & Harrington1995)	Organizing for improvement	Understanding the Process		Streamlining the process	Implementation, measurements & controls Continuous improvement

Tools, point-of-views and focus of the different methods differ. For example, *theory of constraints* (TOC) is about managing the weakest subprocesses or bottlenecks in the system in order to speed up the performance of the whole system (Nave 2002). The purpose of *Six Sigma DMAIC*, which derives from words Define-Measure-Analyze-Improve-Control, is to reduce variation and, thus, improve the quality of the process and the process outputs (Shankar 2009). Respectively, *Lean* process improvement is focused on removing waste (Andersson et al. 2006; Hines et al. 2010). The applicability of the Lean process improvement methodology to service processes has been criticized. In many cases, for example, the pull is in the system naturally, as all the work orders come straight from the customer (Maleyeff, 2006). The process flow is not naturally visible as it is in manufacturing, and therefore new means should be invented to track the projects (George 2003, pp. 255-258).

In addition, the level of improvement differs. *Business process re-engineering* (BPR) is considered as a radical approach that creates the redesign from the scratch whereas business process improvement (BPI) and quick hits, like Kaizen workshops in Lean philosophy, are incremental approaches. BPI aims for low risk and easily achievable efforts by small changes based on the current state analysis. (Dumas et al. 2013, p. 261; Paper 1998; Shin & Jemella 2002; Zellner 2011)

Although DMAIC is mainly associated with Six Sigma, it can be equally applied in Lean process improvement as well. The challenge of Six Sigma improvement is that in some processes no data is available to measure (Antony 2006), but it does not mean that the DMAIC could not be applied at all. DMAIC can be conducted using a Kaizen workshop, where the whole cycle is executed during the event, but the emphasis is more on Lean than on Six Sigma (George 2010, pp. 119-123). The tools and methods used in the improvement project are more relevant than how the improvement process steps are constructed (Chiarini 2012, pp. 23, 44; Montgomery 2010). It is a good practice to combine the methods in the most suitable manner for each process improvement project as they all have their strengths and weaknesses (Andersson et al. 2006).

However, as Medinilla (2014, pp. 114-115) points out, the tools and techniques that the chosen framework provides should not be left out without further analysis. If the tool or the technique does not seem suitable for the situation or there are not enough resources to apply them, the improvement target could lie in the very area of why some techniques and tools are not applicable. Next, the subsections of the chapter describe the basic framework of process improvement and compare different views from different approaches.

2.2.1 Phase 1 - Identification

Process improvement lifecycle begins with process identification. In Six Sigma DMAIC, the first step is called *define.* The purpose of the phase is to select the processes to focus on and identify the demand for change. The selection should be justified by the stress on the process, meaning that the process is suspected to have opportunities to improve (Guha & Kettinger, 1993). It is important to have a clear objective and measurable goals. There should be a common overview of all the processes in an organization and of the relations between them. The process models at this point are vague, and they are defined in more detail in the following phases. (Adesola & Baines 2005; Dumas et al. 2013, pp. 33-34; Harrington &

Harrington 1995, pp. 340-341; Malinova & Mendling 2018; Meran et al. 2013; Taghizadegan 2013, pp. 8-9)

Six Sigma emphasizes that the customers of the process and customer requirements should be identified in the very beginning. It can be done with a SIPOC process map, for example. It is a tool to define the suppliers, the inputs, the outputs and the customers of the process along with the process step. It provides a high-level description of the current process model. (Antony 2006; Meran et al. 2013; Taghizadegan 2013, pp. 8-9)

In addition, the stakeholders and resources are defined (Adesola & Baines 2005; Antony 2006; Dumas et al. 2013, pp. 33-34; Lee & Chuah 2001; Malinova & Mendling 2018; Taghizadegan, 2013, pp. 8-9). The process improvement team should consist of employees who are involved in the process. Kaizen, a continuous improvement methodology in Lean, recommends employees to participate actively in the process design. (Fleischmann et al. 2012, p. 171) In order to obtain the employees approval for upcoming changes, they should be engaged into the process improvement and included in decision making. (George 2003, pp. 255-258; Harrington & Harrington 1995, p. 132; Vandeveer & Menefee 2006)

2.2.2 Phase 2 – Discovery

In order to make redesign and optimize processes, the current process model, also known as the as-is model, should be carefully defined and understood (Adesola & Baines 2005; Dumas 2013, pp. 155-156; Fleischmann et al. 2012, p. 164; Paper 1998; Schwegmann & Laske 2003, p. 107). The process cannot be thoroughly understood until all the necessary information is gathered. Respectively, the process cannot be analyzed and redesigned, before it is understood. (Guha & Kettinger 1993) Employees should be involved in both creating the as-is model as well as in the redesign phase (Malinova & Mendling 2018).

The discovery phase acts as an iterative manner as the understanding of the process grows (Paper 1998), and quick fixes can be executed already at this point if low-effort solutions emerge. Describing the as-is process creates an opportunity to reveal the activities that are not performed or are performed against the organizational instruction, which enables the standardization of the work among all employees. (Harrington & Harrington 1995, p. 345)

According to Meran et al. (2013), the Six Sigma DMAIC *measure* phase consists of:

- Deriving measurements
- Collecting data
- Understanding the process
- Calculating the process,

which serves the thorough creation of the as-is model. Even though the Six Sigma DMAIC suggests measure as a phase that utilizes quantitative data, qualitative methods should be applied in process improvement as well. Quantitative methods fail to describe and identify system structures and processes, feedbacks and their relationships, and therefore, qualitative methods are required in process discovery as well. (Fleischmann et al. 2012, p. 164; Green & Gabor 2012, pp. 85, 99; Harrington & Harrington 1995, p. 418) It is important that the process discovery is based on timely and accurate information (Malinova & Mendling 2018). Data collection is recognized of its problematic nature within process improvement. Even if the data is known to exist, the difficulties might lie in the accessing the data or analyzing the data. (George 2003, pp. 256-257)

Qualitative data collection methods

Qualitative methods are used to understand the process in depth, to listen to the employees involved and to identify improvement targets. Toikko & Rantanen (2009) and Vandeveer & Menefee (2006) emphasize the importance of the participation of the employees involved in the subject. Development is highly dependent on the commitment and activity of the employees. Different perspectives should be shared within the group to achieve common understanding. The key for successful development is a common dialogue where every perspective is listened and considered. By enabling the employees to participate in the decision-making of the possible improvements to-be-made within the team, they are likely to be more committed to adopt the improvements later.

Interviews are based on gaining information about the process from the experts working in the process. The difficulty is that several people must be interviewed in order to gain a complete view of the process as the process knowledge is often shattered to different people. The strength is that interviews can reveal different views on how the process operates. Interviewing often requires multiple iterations. In the last interview the process model obtains an accepted state, and the interviews before that are supposed to clarify the process step by step and to make the interviewees feel more comfortable during iterations. Interviews can be constructed in downstream or upstream perspective. In downstream perspective, the process is studied from the output to the input, and in upstream from input to output. It should be noted, that the interviewees often describe the process based on the assumption that everything works. Therefore, in some cases, it is required to construct the interview in a manner that is able to reveal the exceptions occurring in the process. (Dumas 2013, pp. 162-164)

Workshops act as an open discussion platform between the stakeholders. A common method to use workshops in the process discovery is to let the participants build a map of the process using sticky notes. Usually the process mapping takes more than one day. Some inconsistencies that appear can be resolved immediately at the workshop. (Dumas 2013, pp. 164-165; Schwegmann & Laske 2003, pp. 117-118) Interviews can provide a more confidential platform for the employees to share their knowledge (Brinkmann 2013, p. 27). Dumas et al. (2013, p. 178) recommends using both interviews and workshop-based process discovery methods to gain a complete overview of the process.

Another issue concerning qualitative data collection methods is the lack of objectivity (Corbin & Strauss 2012; Denscombe 2009, p. 152). In interviews and workshops the objectivity is often even more limited. The employees might give false information about the processes if their understanding is limited or they can hide certain issues if they feel that something is obvious to the researcher, for example. (Dumas et al. 2013, pp. 165-166; Schwegmann & Laske 2003, pp. 107-108)

In *observation*, the process is followed in practice, for example seeing an individual case going through the process steps. It gives a good overview on how the process is executed in reality and in the present state of the process. (Dumas 2013, pp. 161-162) Even though observation can be seen as an intrusive and time-consuming method, it has an ability to provide information that could be hidden in the interviews and workshops, and therefore, enables the researcher to achieve a more objective perspective (Corbin & Strauss 2008, p. 28; Sanger 1996, pp. 28-36). However, observing easily affects to the behavior of the employee, and therefore, it might not give the right view about the process (Dumas 2013, pp. 161-162).

Employees can be concerned when they are aware that changes are to be made in their daily work. They might be afraid that their failing is revealed, or they lose their jobs due to changes that follow the interviews, workshops or observation. However, involving the employees in the process improvement and decision-making can reduce resistance in implementing the changes. (Sanger 1996, p. 29; Vandeveer & Menefee 2006)

Document analysis can be done if there is documentation available related to the process. Organizational charts, for example, can provide some information about the process. However, the documentation does not always describe the reality and it can be outdated. The level of detail and the accuracy of the documentation is not always good enough for process discovery. (Dumas 2013, p. 161; Malinova & Mendling 2018; Schwegmann & Laske 2003, pp. 109-110)

Quantitative data collection methods

Measuring the process is a key activity in Six Sigma. However, in service processes it is often challenging to collect quantitative data (George 2003, pp. 256-257). Measurements can be improved by improving the process to be measured (Harrington & Harrington 1995, p. 419).

Performance goals provide the metric for judging the success of the changes made in the process (Guha & Kettinger 1993). By measures, it is easy to target employees' attention to the key points in their work and it encourages them to accomplish clear targets and improve in their work. Measurement creates an opportunity to reward employees when they succeed. Its primary function should be a guiding and motivating tool rather than a tool for strict control and follow-up of the employees. (Uusi-Rauva 1996, pp. 22-24)

Process performance can be measured from several perspectives, like time, cost, quality and flexibility. The choice of measure depends on the process to be measured, the objectives and the data that is available. Quantitative analysis and measuring can be conducted using flow analysis, queuing theory or simulation, for example. (Dumas et al. 2013, p. 214)

A common measure used in analysis is *time*. Throughput time means the time that passes from the start of the work to finishing up the work with a single case. It involves processing time, the active time that the resources actually use to get the work finished, and the waiting time, where the resources do not actually handle the case and it is for example in a queue. (Breyfogle 2003, p. 190; Dumas et al. 2013, p. 214; Fleischmann et al. 2012. p. 162) The aim can be set to reduce the throughput time or meet the defined throughput time without delays. These objectives can be achieved by making changes in the processing time and waiting time. The Six Sigma approach is to reduce variation in throughput time, meaning that the majority of the cases go through the process in the same time. (Dumas et al. 2013, p. 214) Lean approach focuses on eliminating the waiting time to follow the push-pull and just-in-time principles and reducing other waste in the process to reduce the throughput time. Reducing the throughput time can reduce the number of defective units and improve process performance (Breyfogle 2003, p. 191). Other usage for time as a measure can concern in capacity planning, constraint management, performance appraisal and scheduling. (Krajewski et al. 2016, p. 86)

Quality can be measured from the external quality perspective or the internal quality perspective. External quality concerns the process customer satisfaction to the delivered output. Issues include factors like the output amount, relevance, quality and timeliness. Internal quality is about how the process participants feel about their work. It can be measured by the level of variation, empowerment or difficulties experienced in the process. (Davenport & Short 1990; Dumas et al. 2013) Process quality has direct relations to other measures. For example, measuring timeliness does not only concern quality but time as well. (Dumas et al. 2013, p. 215)

In engineering activities, the quality of the work has a great impact in the overall delivery process. Low quality in design affects negatively to both internal and external customers. Faulty designs released into production require an enormous time of repair work, which further affects to the delivery time to the external customer by causing delays. In addition, if the defects are not noticed, the external customer receives a product with low quality. (Muntslag 1993, pp. 139, 227-229) According to Ullman (2010), the overall costs can be reduced up to 75 % with high-quality design.

Quality can be alternatively measured by the number of defects (Guha & Kettinger 1993). A defect per unit (DPU) is a simple measure that describes the quality of the final product. However, it has no link to the process related to the product. In contrary, Six Sigma uses defects per million opportunities (DPMO) as a measure for quality performance. Whereas DPU only defines the final outcome, DPMO focuses on the opportunities for error which gives a more valuable view of the process quality. (Sahay 2015, p. 27)

Sahay (2015, p. 151) explains the link between product quality and processes. If a process is not stable, the outcome is unpredictable, and the products will not meet the requirements. Respectively, well-structured and controlled processes produce acceptable products that meet the requirements.

Cost reduction is another common objective. However, Davenport & Short (1990) state that it is an insufficient measure if not combined with other measures. In most cases, cost can be reduced by improving other measures. Process costs are the expenses required to execute a process instance. Cost comprises of fixed, variable and operational costs. Operational costs are directly related to the outputs of a business process, for example labor cost. (Dumas et al. 2013, p. 215; Fleischmann et al. 2012, pp. 160-161)

The flexibility means the ability of the process to adapt to changing situations. It can be examined from different point of views. Firstly, flexibility can concern how different situations and variations are handled in the process and how the process supports variation and surprises. On the other hand, it can be seen as an ability of the process itself to change. (Dumas et al. 2013, pp. 215-216)

Even though the main objective might differ, the improvement actions of each approach can reach the same secondary effects such as less waste, less variation, improved quality and shorter throughput time (Guha & Kettinger 1993; Nave 2002). It is argued if the process improvement is rather art than science (Zellner 2011), and therefore the improvement framework does not have to be that strict – only the tools and results count. An optimal process produces high-quality products quickly with low cost. Ideally, improving one dimension improves another one as well (Fleischmann et al. 2012, p. 162).

However, it is important to understand the secondary effects of improving one performance dimension. This is illustrated by the Devil's Quadrangle shown in Figure 1. By focusing on improving only one dimension, it might have negative effects to another. For example, if the objective is to reduce throughput time, it might affect to the output quality if both aspects are not taken into consideration. Therefore, other dimensions should be measured in addition to the prioritized measure. (Dumas et al. 2013, p. 259; Fleischmann et al. 2012, pp. 162-163)

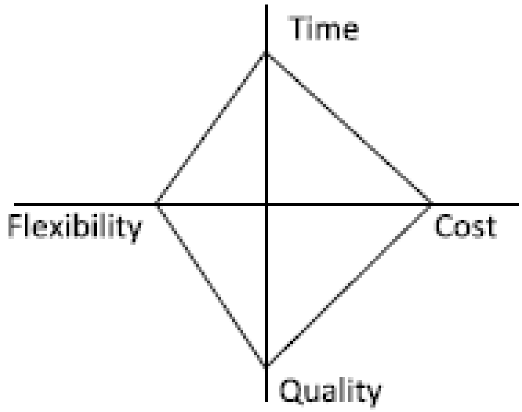

Figure 1. Devil's Quadrangle illustrates that change in a dimension has an impact to another dimension in the quadrangle (Dumas et al. 2013, p. 259).

2.2.3 Phase 3 – Analysis

Analyzing phase in DMAIC is about analyzing the value of the process steps, and identifying and understanding the root causes. In addition to the process analysis, the validity and reliability of the data collected in the previous phase is analyzed. (Antony 2006; Meran et al. 2013) The analysis aims to provide a framework on how to create the to-be model from the as-is model. It finds means on how to eliminate waste, reduce cycle time and improve the process effectiveness. (Harrington & Harrington 1995, p. 345) Lean and Six Sigma offer several tools in the analysis phase.

Value added analysis

In value added analysis, the value of the process steps is classified, and waste is eliminated. The process steps can be categorized as

- Value adding,
- Non-value adding but necessary, and
- Non-value adding. (Dumas et al. 2013, pp. 185-187)

The idea is to eliminate the non-value adding activities, also known as waste in Lean methodology. Value adding activities are the process steps that take the processed item closer to the wanted output. Non-value adding but necessary activities are required for the process to be operating effectively even though they do not add value to the customer. They are necessary to the business, not to the customer. The steps that do not fit to either of the two categories, are simply non-value adding activities that should be eliminated from the process as they are useless both to the process and the customer. The meaning of the non-value adding but necessary steps should be carefully examined and consider if they could be eliminated as well. (Dumas et al. 2013, pp. 186-190; Paper 1998)

Eliminating waste or non-value adding steps can mean that activities are moved to another process. The effect of transferring an activity into another process should be considered in the whole business context. For example, the amount of information to be transported from the first process to another one might decrease, and therefore the change would be beneficial to both processes. On the other hand, workload in the second process might increase significantly. (Dumas et al. 2013, p. 190; Paper 1998)

Another approach to improve the process performance is to automatize value adding or value adding but necessary steps. Utilizing software and adding functionalities in information systems releases the employees to spend their time in knowledge-intensive tasks. (George 2003, p. 360) Automatization can decrease the throughput time by faster job completion and, in addition, by reducing the number of defects and thus, the amount of rework. (de Souza & Carpinetti 2014)

In service operations, the meaning of waste is somewhat different than in manufacturing. Storing of information does not require physical space and, ideally, the information is easy to access in the database. However, in many cases, knowledge is difficult to store and find. Transportation of electronic data, respectively, does not add time to the total lead-time. The order in which activities are executed is not that meaningful as the service processes are more flexible – they do not concern any machines. (Dumas et al. 2013, pp. 257-258) There are several interpretations of the manufacturing waste to office waste. Table 2 describes the interpretations adapted from George (2003), Maleyeff (2006) and de Souza & Carpinetti (2014).

Table 2. Waste in service operations.

Category of waste	Explanation	Example	Authors
Overprocessing	Doing work that does not add value to the process customer	Unnecessary approvals, hand-offs or reviews	George (2003, pp. 259-262) Maleyeff (2006) de Souza & Carpinetti (2014)
Transportation	Unnecessary movement of materials, products or information	Transportation of information (virtually or physically)	George (2003, pp. 259-262) Maleyeff (2006) de Souza & Carpinetti (2014)
Motion	Unnecessary movement of people	Motion between offices Searching for information from the systems	George (2003, pp. 259-262) Maleyeff (2006) de Souza & Carpinetti (2014)
Inventory	Unnecessary work-in-process	Email inbox full of unread mails	George (2003, pp. 259-262) de Souza & Carpinetti (2014)
Waiting	Delay between process steps	People being interrupted Waiting for information	George (2003, pp. 259-262) Maleyeff (2006) de Souza & Carpinetti (2014)
Defects	Any aspect that does not conform to customer needs	Mistakes in design Missing/inadequate information	George (2003, pp. 259-262) Maleyeff (2006) de Souza & Carpinetti (2014)
Overproduction	Producing service or production that is not for immediate use	Producing information or design that is not used soon	George (2003, pp. 259-262) de Souza & Carpinetti (2014)
Duplication	Activity that are done elsewhere in the system or performed more than once	Entering data onto a form at two different locations in the system Reinventing the wheel	Maleyeff (2006) de Souza & Carpinetti (2014)
Inefficient use of resources	Wasteful way of management of personnel, equipment, materials or capital	Creating a work schedule that does not coincide with customer demand Holding meetings that do not add value Ineffective knowledge sharing Underestimated potential of people Inadequate tools available Lack of standardization in routine activities	Maleyeff (2006) de Souza & Carpinetti (2014)

Finding the causes

Root cause analysis focuses on the reasons behind the issues identified. For example, using interviews, the same issue can be described from different perspectives with different stakeholder. The issues usually occur more as phenomena and do not reveal much of the root cause. Therefore, root cause analysis is extremely important in issue solving and different stakeholder perspectives should be thoroughly analyzed to find the actual root causes behind the issues. (Dumas et al. 2013, pp. 191-192; Fleischmann et al. 2012, p. 168)

The next step after the identification of the root causes is to understand the impact of the issues. The issues should be prioritized in order to make a decision in to which issues the process improvement project should concentrate on. In addition, their qualitative and quantitative impact should be evaluated. Qualitative impact might be, for example, the level of customer or employee satisfaction. Quantitative impact refers to measures, like time loss or excess costs. (Dumas et al. 2013, pp. 198-199)

Issue impact can be assessed using a Pareto analysis or 80-20 principle. The basic assumption of Pareto analysis is that a small number of factors cause the largest share of a given impact. To visualize the impact of the issues, tools like Pareto chart and PICK chart can be used. (Dumas et al. 2013, pp. 201-204)

2.2.4 Phase 4 – Redesign

Redesign means creating the to-be model of the process. In Six Sigma, the redesign phase is called *improve*. The to-be process model is based on the analysis of the as-is process in the precedent phase. Usually, only minor improvements are implemented into the process and it is made in an iterative manner which helps tracking the effects of each change. (Dumas et al. 2013, p. 261; Harrington & Harrington 1995, p. 345; Meran et al. 2013)

Process redesign is about changing the process operation and behavior. *Operational view* describes the process steps. *Behavioral view* concerns the way and the order of in which the process steps are executed, as well how the activities are scheduled and assigned. Changes can additionally occur in process customers, organization, information, technology and external environment the process is situated in. (Dumas et al. 2013, p. 256)

According to Fleischmann et al. (2011, p. 164) and Guha & Kettinger (1993), the actions to be taken follow these principles:

- Eliminating non-value adding steps
- Assignment of tasks to external service providers
- Compression and integration of several work steps to one step
- Distributing of work steps to multiple resources so that they can be executed simultaneously
- Breaking old patterns and changing the ways of working
- Earlier starting of currently downstream activities
- Providing IT tools for faster and better work completion
- Adding work steps to improve quality and output.

When transferring tasks from the current process to another process, the organizational communication and activity structures can be completely dissolved and redefined. As the employees lose their tasks, the uncertainty might increase within the organization. Therefore, it is important to evaluate the advantages and disadvantages of such decisions. (Fleischmann et al. 2011, pp. 170-171; Harrington & Harrington 1995, p. 347)

High level of business process complexity causes a lot of waste and additional costs to the business. In some cases, complexity reduction can be used instead of moderate process improvement activities. It can be achieved by standardizing and modularizing the subparts of the products or services and the processes used to deliver them. Another approach is to eliminate complete processes or products that do not add enough value to the business. It is a radical approach that creates beneficial results in high-value offering products and services as their processes can operate better when others are eliminated. (George 2003, pp. 144-167)

2.2.5 Phase 5 - Implementation & control

After careful redesign through analysis, measurement and documentation, the changes are implemented (Krajewski et al. 2016, p. 95). When the changes are implemented, the control phase starts as well. The control phase in DMAIC consists of monitoring and controlling the process and ensuring its success (Meran et al. 2013). In monitoring, the process metrics play a key role, as they give feedback about the behavior and success of the implementation of the improvement project. Therefore, it is important to develop measurement system to gain feedback about the process performance in the future (Harrington & Harrington 1995, p. 352).

Controlling enables a new improvement iteration to begin when situations change, or new challenges or opportunities emerge. Most of the process improvement approaches are iterative, which means that the process improvement is restarted from the first phase after the preceding iteration. The level of change should be decided from the very beginning, meaning how radical or moderate the improvement in question is. (Krajewski et al. 2016, p. 96-97; Lee & Chuah 2001)

The implementation and control phase is often the most misperformed part in the process improvement cycle. A common mistake is that the process is redesigned but never actually implemented. Another common mistake is to leave the process uncontrolled and not continuously improved. (Krajewski et al. 2016, pp. 96-97)

According to Liker (2004), if processes are not standardized, they cannot be improved. If processes are followed irregularly, an improvement can be considered as a variation among others, and defects in the process are difficult to identify. George (2003, p. 258) and Maleyeff (2006) state that standardization can improve flexibility as well. Clear, standardized processes enable the identification of atypical situations and thus understanding of what should be done to fulfill the exceptional demand. Clearly structured processes can adapt to changing circumstances with small, partial changes (Becker & Kahn 2003, p. 7). However, the employees are usually against standardization as they feel it reduces their freedom and creativity. Employee engagement in process improvement is, again, the solution to strengthen the comprehension of the employees concerning the improvement actions and ameliorate their attitude towards standardization. (George 2003, pp. 255-258; Harrington & Harrington 1995, p. 132) In addition, it should be noted that a certain amount of variation in working habits allows the employees to use their own best practices which can be highly beneficial for performance (Hamel 2007).

2.3 Engineer-to-order production system and its challenges

Engineer-to-order type of design and production processes have the least knowledge about what is to come compared to make-to-stock, assembly-to-order and make-to-order processes. Only after the customer has confirmed the order, it is possible to know what material should be ordered and what should be manufactured. Whereas in other systems the time spent to manufacturing is usually the main concern, in ETO systems the time spent on engineering and design affects significantly to the total delivery time as well. (Bertrand & Muntslag 1993)

Product configuration is used as a basis for the ETO products. In addition, reference data is used as the key knowledge base for ETO design activities. The reference data means utilizing solutions from previous ETO projects. When the reference data is recorded appropriately, it can improve the efficiency of the engineering processes. (Bertrand & Muntslag 1993; Little et al. 2000; Schönsleben et al. 2017; Van Veen 1991, pp. 27-28) In many cases, the knowledge of previous ETO projects is difficult to obtain as it is mostly in the memory of the engineers. Therefore, attention should be put in information and knowledge sharing systems in ETO processes. (Willner et al. 2014)

The processes in ETO systems are unpredictable and uncertain as they usually contain a lot of variation (Bertrand & Muntslag 1993). Inefficient product specification and configuration, inaccurate design capacity planning, high level of rework, and late deliveries are common issues in ETO processes. (Little et al. 2000) For example, there might be a requirement for special customer specific components for which the delivery time might be longer than the actual delivery time of the end-product. The cost of design might become more than expected if it requires overtime and extra work hours, thus, causing delay in other projects. The capacity is often divided both in realizing confirmed orders and consulting in quotation phase. (Bertrand & Muntslag 1993)

2.4 Order-specific engineering team in case company

The case company manufactures frequency converters using configure-to-order (CTO) and engineer-to-order (ETO) strategies. Single drives can be either CTO products or ETO products. Drives controlling several motors, also known as Multidrives, are always custom-made ETO products.

The OSE team acts as an independent function that is separated from product development and product engineering. Product development team designs the standard products and product engineering team is responsible for planning and implementing changes to released products. The standard products generated from the product configurator are the basis for ETO products. The OSE team makes modifications to the standard products according to the customer requirements. The customization can be only a minor change to the standard product. Often the ordered applications are common and frequently realized, and hence the design can be made effortlessly based on knowledge of previous experiences. Sometimes, however, customers require a new concept that requires more work and research from the engineers. For the OSE team, it is important to understand to what level the products can be customized in order to avoid changing any critical features in the type approved standard product structure.

As the sales order is confirmed, the OSE team starts working on it. The dimension drawings are made according to the customer specifications and sent to the customer for approval. Once approved, the work is released into production. In the case of Multidrives products, the dimension drawing is made and sent for approval before any other drawings are made. The dimension drawing creates the framework for circuit diagrams and other details. For single drives, all documents can be sent for approval at once because the system is not that complex.

Engineering is often required after the actual engineering phase as well. Customers can change their minds and require new applications or modifications which must be designed into the products. Mistakes or shortages in the drawings or in the part lists, due to engineering or customer, might occur after the design is released to production and production has started, and hence the engineers must make the required corrective changes. Components might be unavailable at the moment and the engineers are required to explore for solutions to replace the component if the delivery time for the original component is too long.

The OSE team consists of project engineering and mechanical engineering as illustrated in Figure 2. Project engineers take care of the whole project and are responsible of communicating with different parties like sales, customer and production. They create circuit diagrams and partlists and handle other documentation. Mechanical engineering acts as a support to the project engineers in cases that require changes to standard mechanics due to customer requests. Mechanical engineering team can be divided in to two sub-teams, the mechanical design and mechanical inspection.

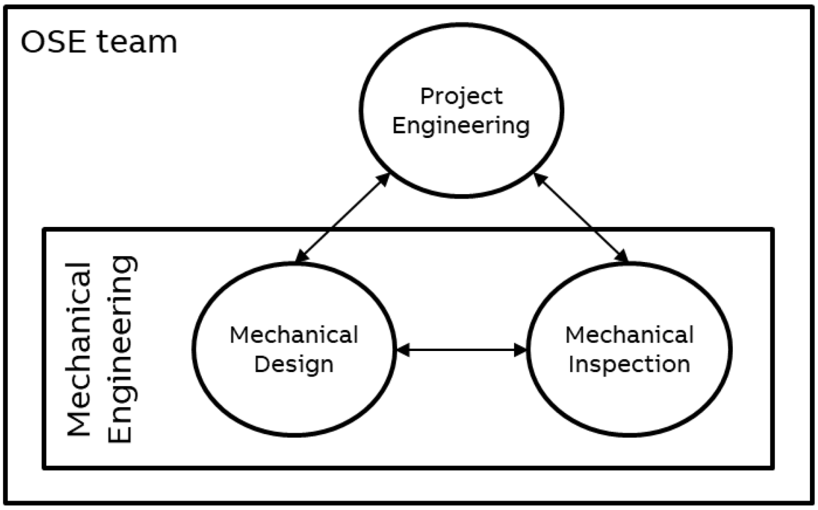

Figure 2. Order-specific engineering team structure in case company.

The mechanical design team creates 3D-models and assembly drawings according to the work requests. Most commonly the requests come from project engineering in the actual engineering phase before the work is released to production. Occasionally, work requests might come after the project is already released into production due to defects, shortages or customer changes. Defects and shortages are majorly caused by errors made in mechanical design or by lack of mechanical design, meaning that the project engineer has not requested any mechanical engineering for the project despite the need.

Mechanical inspection only concerns the ETO process for Multidrives products. In general, it is executed for every Multidrives project. Inspection covers the modifications to bill-of-material (BOM) in the enterprise resource planning (ERP) system and creation of the manufacturing drawing with 2D computer-aided design (CAD) software. The basis of the bill-of-material and manufacturing drawing are generated from the product configurator. The main purpose of the inspection is to make sure that the errors from the generated documents are not released into production.

For single drives, the project engineer takes care of the mechanical inspection, as single drives are simpler systems than Multidrives. Furthermore, manufacturing drawing is not created for single drives. For Multidrives, the manufacturing drawing provides necessary information to assemble the product in a compact form. The manufacturing drawing is a term describing a dimension drawing with a separate manufacturing layer that includes additional information of the project. It is described more precisely in Chapter 4.2.1. The existence of the manufacturing drawing is justified by the aid it provides to the assemblers as they have an overview of the product and mechanical details. The number of other documents needed to describe the product and its assembly is vast, and they are printed to a production folder for each project, and thus, the folder is large and difficult to use for finding relevant information. The production folders for single drives are usually smaller and the products are usually less complex, hence they are not provided with similar aid as Multidrives.

Sometimes the expertise of the mechanical engineering team is applied before confirming the sales order or approving the dimension drawing. In complex projects or in new applications, the mechanical engineering team can be consulted in the sales quotation phase to make sure that the offered mechanics is feasible. This ensures that the customer is not promised anything more than the engineers can provide.

3 Research methods

The process improvement framework described in Chapter 2.2 was applied in this study by collecting data and analyzing it using different methods. Figure 3 illustrates how the present study serves the process improvement project in the case company. The first phase, selection of the process to be improved, the justification for improvement and the goals for the improvement, was conducted already at the beginning of the study by the thesis advisor as he proposed the subject to the author.

The data collection and analysis were done by applying four different methods. Utilizing mixed methods research enables better understanding of the research problem. It is common that new insights emerge during the research, and therefore the research should be able to response to the changes by applying different methods. Mixed methods provide more thorough analysis and examination of the findings, for example by explaining the relationships between variables from both quantitative and qualitative perspectives. In addition, applying several methods may confirm that the research is valid and reliable as it has a good ability to reveal unexplainable results or insufficient data. (Bryman 2011, pp. 91; Denscombe 2009, p. 109; Saunders et al. 2015, p. 173)

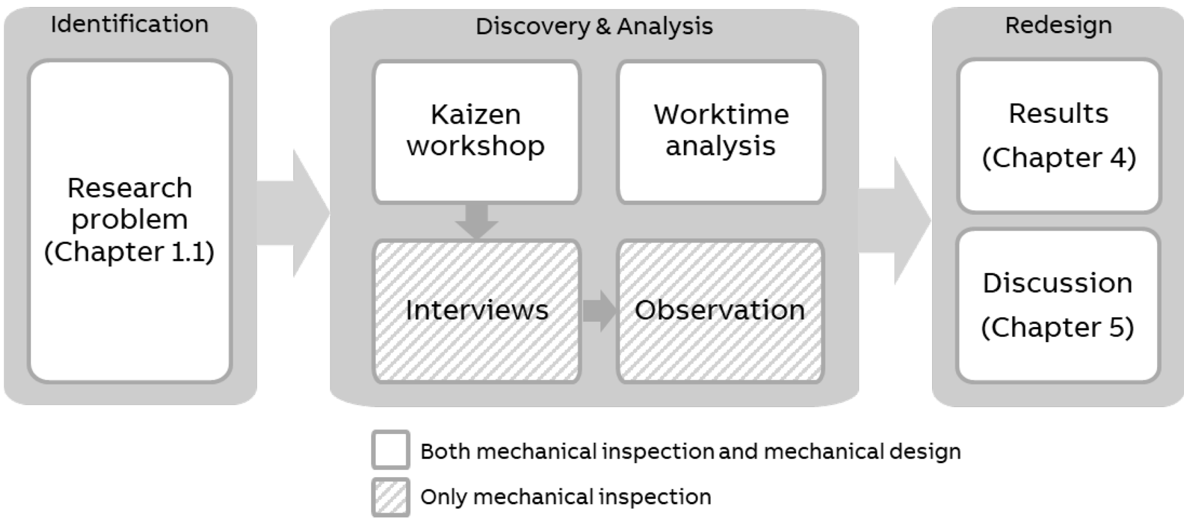

Figure 3. The relationship between the present study and the research methods to the process improvement.

Kaizen workshop acted as an initiative event for the research for both mechanical design and mechanical inspection. It gave an overview about the processes and their challenges and opportunities. It both enhanced the atmosphere of continuous improvement among the team members and provided the author guidelines for how to proceed with the research. Due to the outcomes of the workshop and the discoveries in the workshop, interviews were applied only for mechanical inspection. Next, observation was chosen as a final research method for mechanical inspection. In addition, worktime study was used as a quantitative approach for both teams to support the qualitative methods and to give a guideline for future measurements that can be applied in the process improvement.

3.1 Kaizen workshop

The case company utilizes Kaizen workshops regularly as a continuous improvement tool. It has proven to be an efficient tool for defining the problems, root causes and prioritization within the processes. Kaizen is a Japanese term for continuous improvement. Its basic belief is that every individual can improve their work. It aims to improve quality, productivity and delivery times with reduced costs by eliminating waste in the processes. (García-Alcaraz et al. 2017; George 2010, p. 118; Medinilla 2014 pp. 4-6, 10-18; Taghizadegan 2013, pp. 151-152)

Kaizen workshops, or events, are a major part of Kaizen methodology. Workshops can be adapted in different ways for different purposes as long as they follow the core principles of Kaizen. (George 2003, pp. 266-267; Medinilla 2014) The aim is to find ways to improve and ways to implement the improvements (Medinilla 2014; Taghizadegan 2013, p. 152). After defining the processes, the improvement ideas can be identified, evaluated and prioritized by finding the root causes. (Burton & Boeder 2003, pp. 84-85; García-Alcaraz et al. 2017, p. 98; George 2010, p. 127) The tools utilized in Kaizen workshops are common Lean and Six Sigma tools (Burton & Boeder 2003, p. 84; George 2010, p. 122; Melnyk et al. 1998). Every tool introduced in Lean and Six Sigma is not applicable to all situations. Therefore, it should be carefully evaluated which tools suit best for each case. (Motwani et al. 2012, pp. 30-33)

The Kaizen team should consist of the people who work with the process daily (Bradley & Willet 2004; George 2010, p. 119). Both mechanical design and inspection teams were involved in the workshop. The need emerged before the workshop when an employee stated that the mechanical engineering process is vague. In addition, there was an aspiration to integrate the design and inspection team to some extent. In the common workshop, both teams were able to learn from the other team. It created an opportunity to identify possible solutions to integrate their work. According to García-Alcaraz et al. (2017, p. 138), George (2010, p. 127) and Medinilla (2014), it is essential that every participant understands and agrees with the current state of the process before any improvement actions are made. The participants should be encouraged to share their knowledge and perspectives in order to build enthusiasm and commitment to gain the best results and to help in realization of the results.

Even though cross-functionality can be defined as a key aspect in Kaizen workshops, executing a workshop with non-cross-functional team does not rule out success. In their study, Farris et al. (2009) discovered that in some cases cross-functional team might even be harmful for the execution of the workshop. As the purpose in the present study was to mainly focus on the internal processes and gain fruitful discussion among the team members, the suppliers and customers of the process were left out, and only mechanical engineering team was involved in the workshop. However, as the interaction with project engineering is close, the project engineering manager was invited to the event to enable understanding the interaction between mechanical engineering and project engineering.

The involvement of management has proven to have a significant impact in the previous studies (Farris et al. 2009), which was taken into account in the planning of the workshop. In addition to the project engineering manager, the new mechanical team leader was involved in the planning and leading of the workshop, and the head of OSE department attended to show his approval and commitment to the workshop.

The author led the workshop. Before the workshop was organized for the present study, the author attended to other unrelated workshops held in the case company and learned about the Kaizen concept. Experienced Kaizen leaders in the company were interviewed to gain their knowledge about organizing a workshop.

Kaizen workshop acted as an opening event for the present study, which means that it provided information about how to proceed with the study. The purpose was to gather the team and the managers at the same place, out of their daily work environment, to define and examine their processes. A secondary objective was to enhance the atmosphere of continuous improvement and give tools for the team to improve in the future.

Kaizen workshops are usually week-long events, but they can be successful when applied in shorter periods such as half a day as well (George 2003, p. 265). In the present study, the Kaizen workshop was not utilized as a single improvement method, and therefore a one-day workshop was seen appropriate.

The workshop in the present study consisted of the following steps:

1. Defining the processes using a SIPOC diagram
2. Identifying pain in the processes
3. Creating a pain and frequency prioritization matrix
4. Defining the required key changes
5. Creating a benefit and effort matrix.

The workshop started with going through the whole process of mechanical engineering. The processes were explored using a SIPOC model where the suppliers, inputs, outputs and customers of the process are described along with the process steps. Then, the pain in the processes was identified. The weaknesses and waste were pointed out visually in the SIPOC to the process steps or other items, like suppliers or outputs.

Next, the pains were ranked by their frequency and level of impact. The prioritization of the issues to be handled was conducted with *the pain and frequency prioritization matrix*. It is shown in Figure 4. The purpose of the matrix is to evaluate which issues occur frequently and what is their impact on the process. Frequent issues that cause a lot of pain are located in the upper right corner of the matrix and they are the issues that should be in the focus at the next process steps. Low-priority issues are seldom and do not cause high amount of pain, and therefore, it is usually not profitable to focus on them.

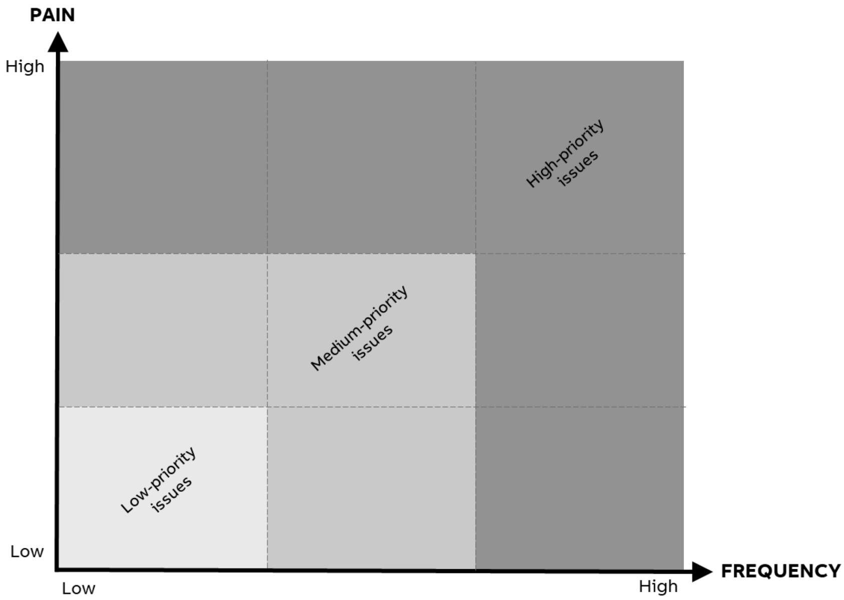

Figure 4. Pain and frequency matrix helps identifying the significance of the pains by the amount of pain they cause and by the frequency they occur.

To solve the issues, required key changes were defined and discussed. After defining the key changes, they were evaluated using a benefit and effort matrix, which is also known as PICK chart (Dumas et al. 2013, pp. 203-204). It is shown in Figure 5. It is another tool that aids in prioritizing among several topics. The changes which can be made with low effort and which gain a lot of benefit are located in the lightest gray area. The low-effort and high-benefit changes are most commonly chosen to be implemented in Kaizen workshops. The changes in the darker grey areas, where changes require medium to high effort and have medium to low benefit, require longer time to be solved, and therefore they are not suitable for fast Kaizen improvement. (George 2010, pp. 120-121)

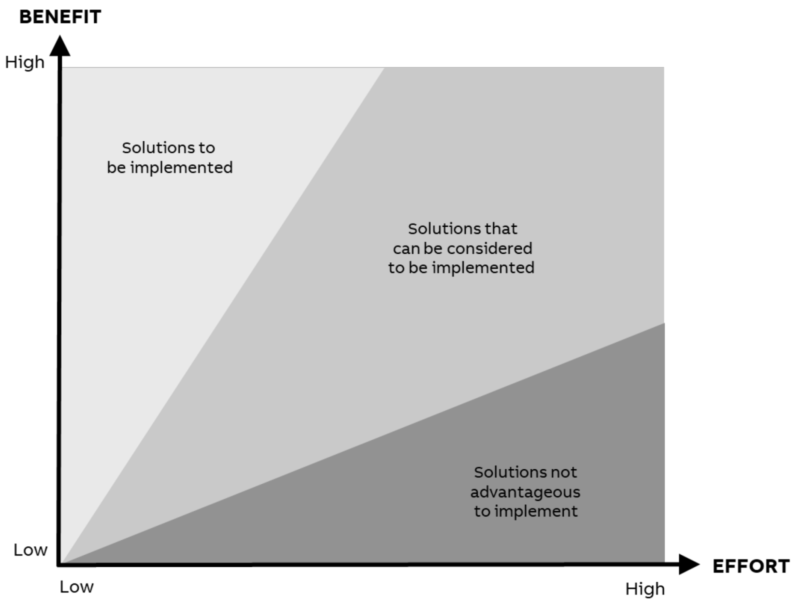

Figure 5. Benefit and effort matrix helps prioritizing the solutions by the level of benefit they produce and by the amount of required effort in implementing them.

3.2 Interviews

Based on the observations in the Kaizen workshop, as discussed later in Chapter 4, the interviews were conducted for mechanical inspection. The workshop showed that the mechanical inspection requires more thorough analysis than the design team, and therefore it was decided to focus on the inspection. In addition, production employees were interviewed to find out their perspectives about the manufacturing drawing.

3.2.1 Mechanical inspection

Group conversations, such as workshops, represent collective opinions and perspectives, but it is important to listen to individuals, as well. Individual interviews go through the views of an employee about their job and provide knowledge for the research. Individual interview provides a greater opportunity for the researcher to lead the conversation to the desired direction as it is usually less lively than a group conversation, like a workshop. It gives an opportunity to create a more confidential platform if the research subject is sensitive for the employees. (Brinkmann 2013, p. 27)

The interviews in the present study were constructed as semi-structured individual interviews. In semi-structured interviews, the researcher modifies the conversation in the interview so that it serves the agenda (Brinkmann 2013, pp. 21-22). First, the interviewee was asked general questions about their work. The purpose was to get an overview of their feelings, experiences, and attitude towards their job. Interview questions are presented in Appendix 1.

The second part of the interview consisted of a process walk. The process steps and activities were defined again on the basis of the Kaizen workshop. They were written down on sticky notes to visualize the process. According to Crilly et al. (2006) and Törrönen (2017), this type of stimuli can be used to guide the interviews to aid the interview to be of more benefit to the research. It helps to obtain information outside the interview situation and improve communication in the interview. The goal of the process walk was to identify waste in the process and, in addition, to confirm the current state of the process.

3.2.2 Production

Production workers were interviewed in a semi-structured manner. The interviews were inspired by a method of Lean management philosophy called Gemba walk. Gemba is a Japanese term that means the real place. The key idea is to go where the actual work takes place and that the employees at Gemba, the workplace, are be listened by the management and the possible problems solved at Gemba. (Imai 1997, p. 13-17)

Gemba walks are another tool that encourages employee commitment besides Kaizen workshop. Gemba walks can result in long-term benefits regarding gained credibility and respect. Stepping down to the employee-level and dedicating time and effort in understanding employees build trust and commitment. It can nurture the employees' creativity and new ideas might emerge in the discussions. It is important to thoroughly analyze the operations when the people in the decision-making position do not perform the work to be improved by themselves. The most comprehensive method to do it is to gain information from the employees performing the work. The employees will be more adaptable to the changes made if they know they have been listened and have been involved in the decision-making. (Gesinger 2016; Imai 1997, pp. 18-19; Vandeveen & Menefee 2006,

p. 206) Gesinger (2016) states that the purpose of the Gemba walk can be as simple as curiosity. Gemba does not necessarily require any particular problem to be solved. It is a way to learn about the processes and the people, and in addition, improve the overall atmosphere and trust within the company.

In this case, the Gemba locates at the production floor where the assemblers work. The purpose in the present study was to briefly discuss what production requires and expects from mechanical inspection. The focus was mainly on the manufacturing drawing and how the assembly workers utilize it. The purpose is to identify if the time the inspectors spend in creating the manufacturing drawing is valuable to downstream functions.

3.3 Observation

Observational research was adopted as the workshop and interviews did not result outcomes in the desired level of detail. As stated in Chapter 2.2.2, observation as a data collecting method has its drawbacks, for example reducing trust among employees. However, it is an intensive and efficient in revealing information about the process that would not come up with interviews or workshops. Therefore, as the results from interviews and workshops turned out to be insufficient, it was decided to approach the process through observation.

The observational research was another method inspired by Gemba walks introduced in Chapter 3.2.2. Gemba philosophy intends to build trust between the management and the employees, whereas observation easily disrupts it. However, Gemba walks can raise same concerns as observation in the employees if conducted by management (Bremer 2015). Therefore, the observer should take a position of an apprentice rather than a researcher or a manager and aim to combine the observation and Gemba in a manner that benefits from both approaches.

According to Fleischmann et al. (2012, pp. 60-61), apprenticing creates an opportunity for the researcher to gather relevant knowledge in cases where information about the process is difficult to elicit by other means. The observation approach utilized in the present study was participant observation where the researcher takes a position of an apprentice in the mechanical inspection. The observation was executed by performing several inspection cases. Running through the tasks involved in the process provided a good description about the process and its challenges. Going through the process in real life gave valuable and thorough information as all process steps and activities had to be followed, and issues and challenges could not be hidden or passed.

3.4 Work time analysis

Work time was studied to support the qualitative methods. The analysis was conducted with the data already found in the ERP system in which the employees record their work hours for each project. In the present study, the data from the preceding year for both mechanical design and inspection was fetched and analyzed. The use of already existing data is a non-intrusive method compared to actual work time study where the employee performance is measured to their knowledge and where the employees most often are unwilling to cooperate because of fear or confidence (Kanawaty 1992, pp. 25-26). In addition, by utilizing the data in the ERP system, a wider time frame was available for the analysis which can lead to more thorough analysis and widely applicable results.

The purpose of the analysis was to define mean throughput time and find possible abnormalities and assignable causes. In addition, correlation between project characteristics and the throughput time was explored in order to make the capacity planning more accurate. As no process performance measures were in use for the mechanical engineering, the analysis could provide a basis for measuring process performance in the future.

4 Results

This chapter presents the outcomes of the applied research methods. First, findings of the Kaizen workshop are discussed. It provides the initial process descriptions for both mechanical design and inspection. In addition, improvement targets for mainly mechanical design team are introduced. Next, the chapter covers the findings of the other qualitative methods. A more detailed process description of mechanical inspection is presented. The section covers analysis of the mechanical inspection process with a discussion about its challenges and opportunities. The last section presents the findings of the work time analysis for both mechanical design and inspection.

4.1 Findings from the Kaizen workshop

The most important finding of the workshop was based on the observation of the behavior of the team members. The mechanical inspection team had significantly more difficulties in defining their processes and finding issues than the mechanical design team. At this point of the study, it was realized that more focus should be put onto the mechanical inspection. The mechanical design team proved to be fairly creative in process improvement and their capabilities in continuous improvement seemed sufficient. The benefit from the workshop for mechanical design, in addition to the multiple issues and solutions identified, is the tools and methods to use in the future for making changes in their processes.

4.1.1 SIPOC

The process was modelled with sticky notes by the employees, as shown in Figure 6. At this point, it could be observed that the mechanical design process was easier to model than the inspection process. The inspectors found it difficult to describe the process steps in detail, and they seemed frustrated and unwilling to participate.

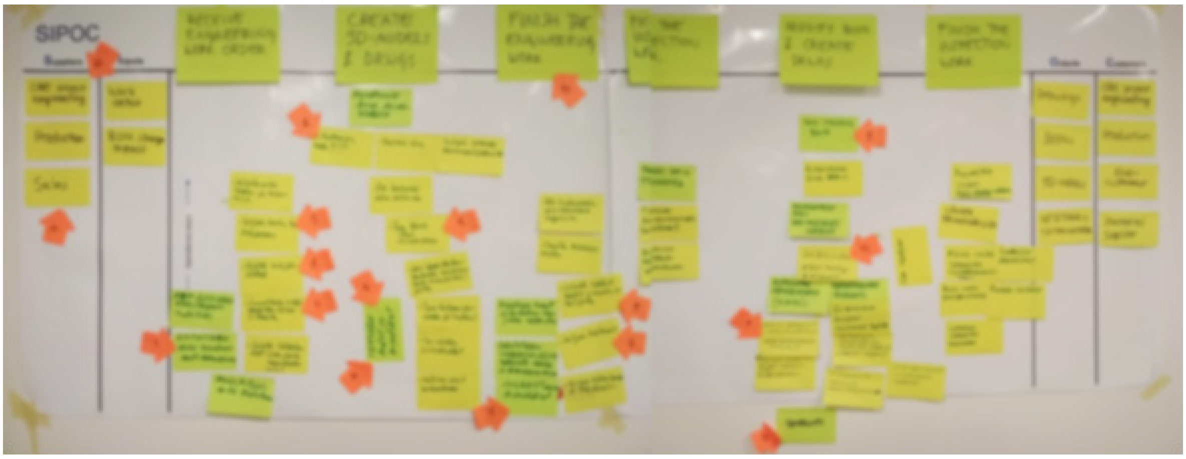

Figure 6. SIPOC diagrams created in the workshop. The suppliers and inputs are on the left, and the customers and outputs on the right. In the middle there are the process steps for both mechanical inspection and design. The orange sticky notes represent the identified pain points.

Figure 7 represents the mechanical design team SIPOC created in the workshop. The mechanical design work orders come via email or as a printed pdf. After receiving the work order, mechanical designer adds it manually to the Excel work queue. According to prioritization, mechanical designer selects a project from the work queue and starts fulfilling the required task. The mechanical design work consists of 3D-modelling of the components, creating the assemblies and BOMs, and creating the 2D-drawings for all models. Depending on the case, the design team communicates with sourcing, production, project engineering or mechanical inspection.

<table>
<tr><th rowspan="2">Suppliers</th><th rowspan="2">Inputs</th><th colspan="5">Process</th><th rowspan="2">Outputs</th><th rowspan="2">Customers</th></tr>
<tr><th colspan="2">Receive work order</th><th colspan="2">Create 3D-models and drawings</th><th>Finish the work</th></tr>
<tr><td rowspan="8">Project engineering

Production

Sales</td><td rowspan="8">Work order</td><td colspan="2">Enter the work order to work queue</td><td colspan="2">Possibly send to the customer for approval</td><td>Send BOMs and drawings to project engineers</td><td rowspan="8">Drawings

BOMs

3D-models

Required communication</td><td rowspan="8">Project engineering

Production

End-customer

Material supplier</td></tr>
<tr><td colspan="2">Decide the working order</td><td>Make component revisions</td><td>Inform sourcing/production/ project engineering about the revisions</td><td>Record work hours and mark work finished in work queue</td></tr>
<tr><td>Find out if the solution already exists</td><td>Find out where to find a reference</td><td colspan="2">Find out if the parts already exist</td><td>Enter the work to Excel database</td></tr>
<tr><td colspan="2">Define and clarify the requirements and source information</td><td colspan="2">Create BOM in Excel and in to the drawing</td><td>Publish the drawings</td></tr>
<tr><td colspan="2" rowspan="4"></td><td colspan="2">Define further the source information</td><td rowspan="4"></td></tr>
<tr><td colspan="2">Create drawings of the assembly</td></tr>
<tr><td colspan="2">Create drawings of the components</td></tr>
<tr><td colspan="2">Model the components into assembly</td></tr>
</table>

Figure 7. Mechanical design SIPOC diagram interpreted from the workshop.

Figure 8 illustrates the SIPOC diagram for mechanical inspection. The project engineer assigns the work in the ERP system and creates a mechanical BOM change request to the ERP system. Usually, the inspectors are additionally informed with a printed copy of the project instruction and dimension drawing. The basis of the BOM and drawings are generated from the product configurator. The inspector modifies them according to the project specifications. The manufacturing drawing is created by adding information on a separate layer in the dimension drawing. The information includes, for example, special mechanics and material codes for the doors, bottom plates, bus bars and lifting beams. The BOM modifications and choice of components are based mainly on utilizing previous knowledge and searching reference from previous cases. If no suitable component exists and 3D-modelling is required, the work is transferred to the mechanical design team. In addition to the manufacturing drawing and modified BOM, the outputs include required information about changes, specialties or need for mechanical design. Whereas SIPOC only provides a high-level process map, the inspection process is described in detail later in Chapter 4.2.1 based on the interviews and observation.

Suppliers	Inputs	Process				Outputs	Customers
		Pick the work from work queue		*Modify BOM & create manufacturing drawing*	*Finish the work*		
Project engineering Production Sales	Work order BOM change request Dimension drawing Preliminary BOM	Find out if the work is already done	Find out where to find a reference	Modify BOM and add required components to BOM	Send special colours list to project engineer Inform project engineer about possible plinths	Manufacturing drawing BOM Required communication	Project engineering Production End-customer
		Pick the work from the work queue in SAP		Add special features, bus bars and holes for doors into manufacturing layer in dimension drawing	Inform project engineer about possible shortages		
				Go through the dimension drawing	Inform project engineer if changes have been made		

Figure 8. Mechanical inspection SIPOC diagram interpreted from the workshop.

4.1.2 Identified improvement targets

The orange arrows earlier in Figure 6 symbolize the pain points identified in the processes. The pains and their solutions are presented in Table 3. The issues are sorted out by the level of pain they cause and the level of benefit their solutions provide. Only one of the solutions concerns merely mechanical inspection, whereas majority of the solutions is for the design team.

Figure 9 and Figure 10 illustrate the information of Table 3 in more visual form. The general way in Kaizen workshops is to drop out the less meaningful issues at the pain-frequency prioritization phase, which is represented in Figure 9, and focus on the issues on the right top corner. However, the participants were keen on discussing the other issues as well, and it was decided to proceed with all pains identified. The opportunity to sit in the same room together and have every team member focus on improvement was unique, and hence it was considered beneficial to utilize it in the best way possible and let the employees to be heard thoroughly.

Table 3. Pains and solutions identified in the workshop and their relationships to each other presented.

PAIN #	PAIN	SOLUTION #	SOLUTION	BENEFIT	EFFORT	TEAM
High-significance pains / high-benefit solutions						
1	The references (model work) are difficult to find	A	Training to use Windchill and find reference cases	H	L	Design
		K	Improving the documentation in Excel	H	H	Both
8	Recording working hours is unclear	H	Instructions for recording work hours	H	L	Design
9	The adding and switching of individual parts is time consuming as the references are hard to find	M	Development of the component lists	H	H	Both
10	Faulty designs are released into production	D	Inspection and verification for work	H	M	Design
11	Best practices in modelling are not known and shared	I	Best practices of modelling with Creo into Confluence	H	M	Design
High-significance pains / medium-benefit solutions						
4	Solving issues related to manufacturability is not clear	B	Contact list of material subcontractors	M	L	Design
		N	Excursions to subcontractors' plants	M	M	Design
7	Technical issues with SAPLink	C	More communication with Creo responsible	M	L	Design
Medium significance pains / high-benefit solutions						
2	Prioritization principles are unclear	J	Mechanical pre-eng team	H	H	Design
3	Receiving workorders and entering them into work queue Excel is time consuming	J	Mechanical pre-eng team	H	H	Both
		G	All work orders should go through pre-eng	H	M	Both
		F	Work orders to a common folder in the network drive	H	L	Design
5	The use of BOM Excel and SAP BOM is not clear and use of both of them causes extra work	L	SAP BOM for application engineered drives that could be copied to SOs	H	L	Design
12	Different sources of work give different source information	J	Mechanical pre-eng team	H	H	Both
13	Dimensioning of busbars (the amount and lengths) is not clear	E	Update the busbar-sheets	H	L	Inspection
15	Sales passes the pre-eng process and asks directly from the mechanical team which reduces transparency of information	J	Mechanical pre-eng team	H	H	Both
No solution						
6	Revisioning of components is unclear	-	-	-	-	Design
14	Space issues regarding door holes in already confirmed orders	-	-	-	-	Both

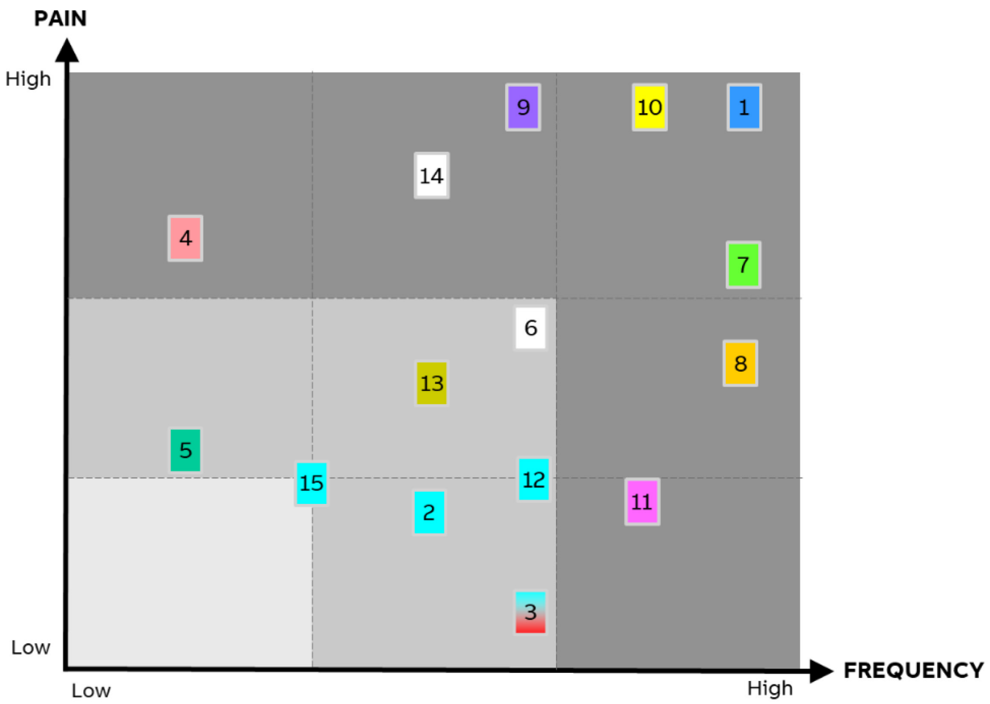

Figure 9. The pains described in pain-frequency matrix. Pains are numbered correspondingly to Table 3. The color of each number is the same as the color of the respective solution in Figure 10.

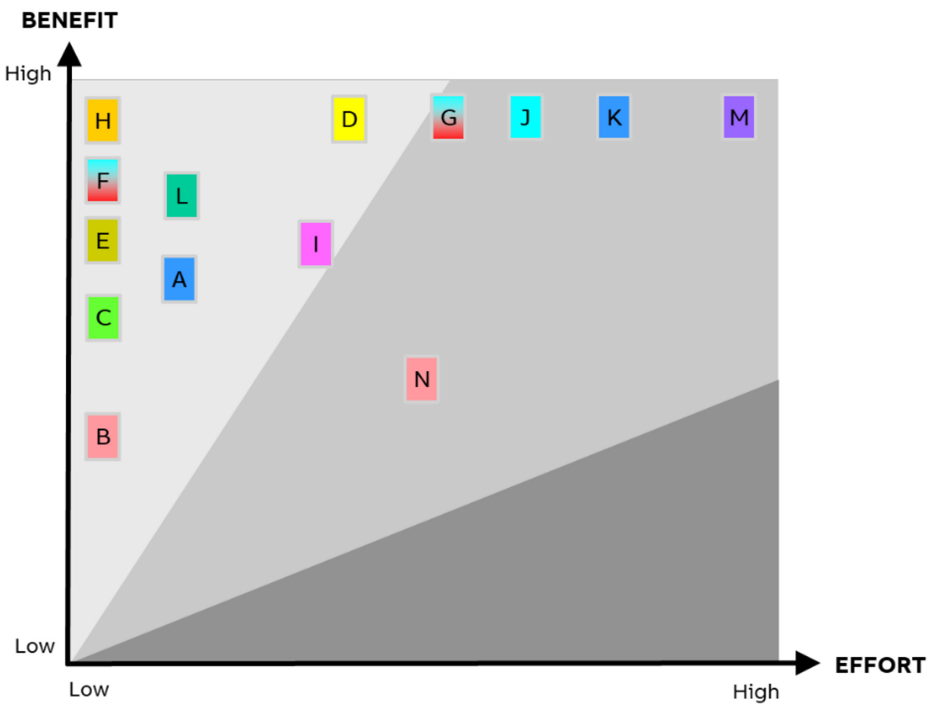

Figure 10. The solutions described in benefit-effort matrix. The solutions are marked with a letter correspondingly to Table 3. The color of each solution is respective the color of the issue, shown in Figure 9.

High-significance pains and high-benefit solutions are located in the dark grey area in the both matrices. However, the solutions K and M require high effort in implementation. They cannot be made in fast pace as the realization should be carefully planned. Additional resources are required to be put to them in order to carry them through.

There are two pains, 7 and 4, located in the dark grey area in the benefit-effort matrix that do not result in high-benefit solutions. The reason behind it could be that the solution is not sufficient to fix the problem. Nevertheless, if they are identified as critical issues, any actions to improve situations should be taken. In addition, the effort is ranked as low to medium, which means that their implementation does not require a great amount of resources.

Respectively, even though the pain and frequency are rated from low to medium (light grey area in the matrix), the benefit from the solution can be seen as high for certain pain-solution combinations. Most probably the issues did not appear painful at the first glance, but as the key changes were brainstormed, the benefits of fixing the issues were seen much higher.

Solution J is repeated for four different pains and therefore it is ranked as highly beneficial. However, it requires high-medium effort, and thus it is situated in the light-grey area of the matrix. The solutions on light-grey area, as mentioned in Chapter 3.1, are not necessarily recommended to be done from the Kaizen methodology perspective. Yet, based on the discussion at the workshop and the enthusiasm arisen regarding the solution, a decision was made to move forward with the implementation.

For two of the pains, 6 and 14, there were no solutions found during the Kaizen workshop due to their complexity. They require more research and it could not be conducted during the workshop as the time was strictly limited. Pain 14 concerns the issue with defining door cut-outs. They are usually made incorrectly into the drawings as they are difficult to define from the office.

4.2 Findings from the interviews and observation

In the individual interview in mechanical inspection, the enthusiasm towards the subject and willingness to participate in the improvement was in a higher level compared to the situation in the workshop. No managers or colleagues were present, and hence thoughts could be shared in a more relaxed environment. Therefore, by the subjective experience of the author, the individual interview was a good approach in order to enhance employee engagement.

In the other interviews, the assembly line workers were asked if the manufacturing drawing is accurate. They were asked to consider if everything in the drawing was useful and if there is something to be added to make their work easier. The aim was to examine how the assembly workers use the manufacturing drawing and to confirm if all the information in it was useful or not.

The observation provided the final ingredients into understanding the process, which, respectively, enabled a comprehensive process description and model. The process analysis and ideas for redesigning the process were conducted based on the interviews and observation.

4.2.1 Final process description for mechanical inspection

Based on the interviews and observation, the process model was finalized and confirmed with the employees. The main-level process flowchart is shown in Figure 11. It describes same information as the SIPOC diagram, Figure 8, in a more detailed form that illustrates how project engineering and mechanical design are involved in the mechanical inspection, and how the decisions are made. Process step *Execute basic inspection* represents the actual inspection work that produces the modified BOM in ERP and the manufacturing drawing as outputs. The tasks that it includes, namely inspecting the BOM and creating the manufacturing drawing, are described next.

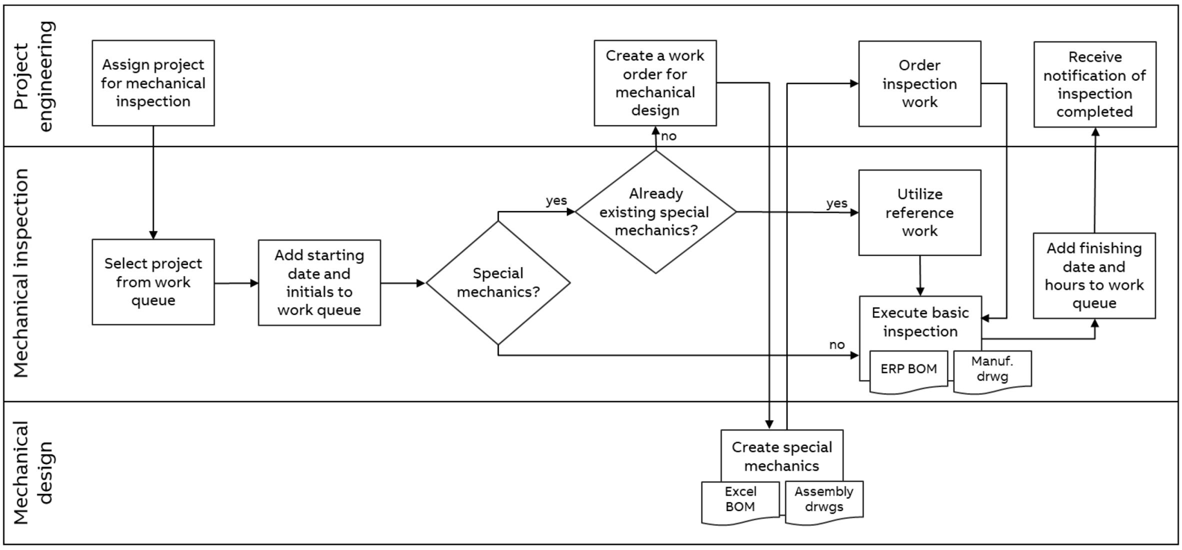

Figure 11. Mechanical inspection process flowchart.

Inspecting the bill-of-material

In principle, the inspection of BOM is carried out by comparing it to the assembly drawing, because the BOM does not always generate according to the drawings and it is vital for production that the correct components are ordered in the very beginning.

The inspection is done systematically in a sequence that follows the device structure illustrated in Figure 12. The inspection usually begins from the first transport length of a lineup, and each unit within the transport length is examined. The BOMs are constructed in a similar order and the components are grouped by their type for each unit, which aids the inspectors to keep to the inspection process. The greatest amount of time is spent on finding the information about the selection of components, which means going through several assembly drawings and possibly different databases in finding a previous project in which the component has been used.

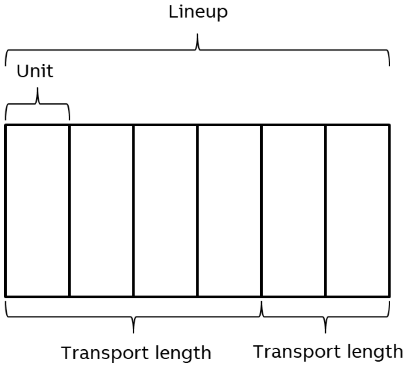

Figure 12. Product structure.

The inspection tasks always include identifying the need, number and type of transport length-specific components, which are common for all the units within the transport length. They are chosen according to general guidelines. These include:

- AC/DC-busbars
- Lifting beams and plates
- Insulating sheets
- End plates.

The inspector evaluates the need for the BOM inspection according to his knowledge and experience. In the case of common, often recurring product variant, the inspector only glances through the BOM. In respect of new, recently released product types, the inspector goes through the BOM component by component. The inspector uses the assembly drawings and interprets them in order to find out, which components should be in the BOM. This is due to the maturity of the product. New or seldomly handled product variants are usually rough versions, because there is most often haste and pressure to get new products sold as soon as possible. Therefore, the BOMs generated from the configurator are expected to have multiple errors and they require supplementary attention. In addition, the products are new to the inspectors as well, and they have to spend time learning about the product in question. Additionally, the inspectors take care of the mechanics of the new special applications that have not been realized before. In these cases, they create a new unit by utilizing suitable components of existing products or assign the design work of new components for the mechanical design team if required.

For the common, well-known products, the inspectors have already learned the components and deficiencies by heart. As these products were released, the inspectors started to give feedback about the detected issues, and as the time has passed, most of the errors have been eliminated. The inspectors can rely on their experience, and fast forward with some of the units they know are most probably generated correctly. The knowledge and experience are extremely valuable, as the amount of time spent on inspection of the familiar cases is significantly less than when going through the BOM row by row.

Creating the manufacturing drawing

Another important task for the inspectors is to make sure that the dimension drawing is accurate, and the configuration is feasible. They add multiple details to the manufacturing layer of the dimension drawing which acts as a summary of the features for the production. The manufacturing layer is illustrated in Figure 13 where the black elements represent the actual dimension drawing and the red elements are the additions that the inspector adds to the drawing. The templates for information are copied from personal cheat sheets in CAD in order to reduce the effort used in formatting.

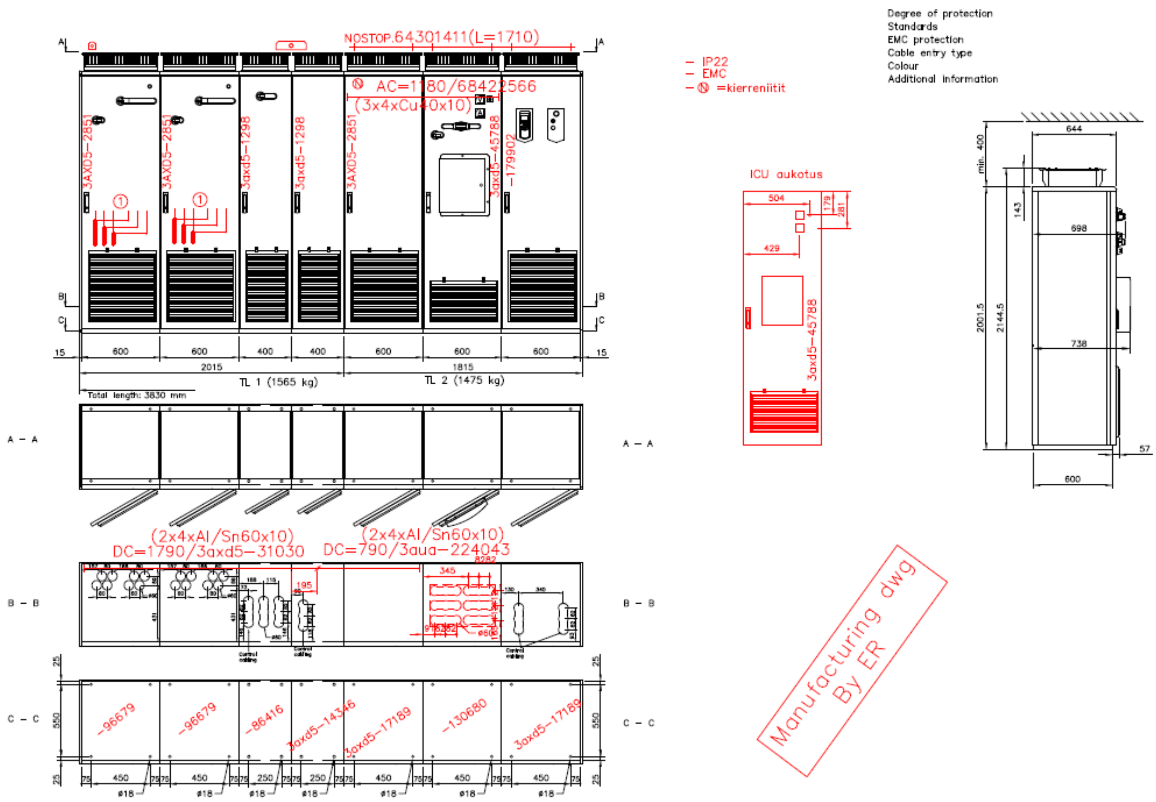

Figure 13. Dimension drawing with manufacturing layer illustrated in red.

The additions to be made in the manufacturing layer include material codes and visual representations of AC/DC-busbars, lifting plates and lifting beams. AC/DC-busbars are positioned in the correct place according to the type of the units. Their length and material are specified in the drawing. Lifting plates and beams are transport length -specific and selected according to the weight of the units.

In addition, material codes for each door and bottom plate is included in the drawing. Depending on if the initial door cut-outs and bottom lead throughs, they are drawn accordingly. If the door cut-outs are non-standard, they are represented in a separate drawing in the sheet as well.

Any special features or features that require special attention, such as switching standard PE-bus bars to special PE-bus bars, fastening between the transport lengths or parallel coupling within a unit are mentioned in the manufacturing drawing, as well. Finally, the name of the inspector and project specifications are mentioned.

4.2.2 Value added analysis in mechanical inspection

Several wastes could be identified based on the interviews and observation. They are listed in Table 4 and categorized according to the office wastes defined in Chapter 2.2.3.

Table 4. Waste identified in mechanical inspection.

Category of waste	Waste identified in case company
Overprocessing	-
Transportation	Ordering mechanical design
Motion	Searching for reference cases
Inventory **Waiting**	Waiting for information regarding a project Interruptions for consultation
Defects	Excess components in BOMs Defining holes for doors incorrectly Delays due to high workload Mistakes in upstream functions
Overproduction	Mistakes in upstream functions
Duplication	Defining holes for doors incorrectly Ordering mechanical design Searching for reference cases Contradictions between the manufacturing drawing and other documents
Inefficient use of resources	Manual work that could be automated Lack of knowledge sharing Low level of employee empowerment

Creating the manufacturing drawing

Even though the information in the manufacturing drawing is found from other documents in the production folder as well, it acts as an important aid in production according to the interviews. Bus bars are the most important feature in the manufacturing drawing, as their positioning is not indicated elsewhere in the documents. Furthermore, manufacturing drawing saves time and effort in finding other key information. In addition, the single drives production craves for a similar manufacturing drawing, which enhances the importance of the creation of the drawing.

Based on the observation and hands-on experience in mechanical inspection, the author did not experience the creation of the manufacturing drawing as an activity taking a significant excessive effort. From author's subjective point-of-view, the manufacturing drawing does not help only the production but the inspection work as well.

The inspector utilizes the dimension drawing as a visual aid to gain a comprehensive overview of the lineup to be inspected and makes notes to the drawing. At least for the author, a straightforward approach is to first define transport length specific components, like bus bars and lifting accessories, to the manufacturing layer, and afterwards add them to the BOM. They are chosen according to the measures of the drives units, which are taken from the dimension drawing, hence defining the bus bars and lifting accessories in the manufacturing drawing is not only an aid for the production but in addition it is an easy way of doing the job for the inspectors. Respectively, the author considers that selecting the doors and bottom plates is the easiest when adding the material codes first in the manufacturing layer and copying them to BOM afterwards.

Rest of the markings illustrated earlier in Figure 13, are added effortlessly from the cheat sheet by only copying, and therefore they do not cause significant amount of excessive work but are helpful in the production. As a conclusion, the creation of the manufacturing drawing creates value to customer, namely production, and is a visual aid in the inspection work as well, hence it is not considered as waste.

Ordering mechanical design

A topic concerning the interaction between mechanical design and inspection emerged already at Kaizen workshop and was again observed during apprenticing. In cases where suitable mechanical application does not exist or cannot be found, the application is ordered from mechanical design. The process is shown earlier in Figure 11. There are multiple steps for a simple request. If mechanical design work is required, the inspector informs the project engineer who makes the work order to the mechanical design team. As the mechanical inspector assigns the work to a designer, he has already thought about the case in depth and the possible solutions for it. Therefore, he must transfer information and explain the case and possible solutions to the designer, which takes time and effort. In addition, despite the explanation, the designer most probably is urged to go through the same information as the inspector in order to understand completely the issue in question.

In addition, duplication exists in these cases, as the mechanical designer creates the BOM in an Excel sheet that is sent through project engineer to mechanical inspection where the components are added to ERP BOM. The BOM is handled twice, even though it could be updated straight to ERP.

Searching for reference cases

As the work is mainly based on finding and applying previous cases with similar applications, it is crucial to find them with low effort. However, sometimes it is considered to be faster to make the work from scratch than to spend time finding the information. Thus, occasionally a case is redone even though there is an exact match somewhere in the system, and components are remodeled even though there a suitable part already exists. Effort should be put in documenting previous cases in a suitable form that information would be found easily.

Waiting for information regarding a project

Waiting emerged in the cases where the reference model was not found instantly or there were some issues with the project specifications. The work cannot be continued, before another party, like project engineering, gives a clarification or a confirmation about an issue. The issue, however, concerns the whole ETO process, including the project engineering and production, as customer approvals and other information are waited for to proceed. Waiting and inventory are caused directly by inefficient processes.

Interruptions for consultation

Interruptions are common in the mechanical inspection. The number of interruptions has diminished significantly due to improvement actions made earlier, and therefore the employees do not feel that the level of interruptions as a waste is disturbing. Interruptions can be seen as non-value adding but necessary activities in the process. Knowledge of the inspectors is required in other processes, for example in project engineering, and by giving consultation, the value is added to the customer in the overall customer delivery process.

Lack of knowledge sharing

During observation, it was noticed that executing mechanical inspection requires a vast amount of knowledge that is mainly stored in the employees' minds. In order to increase mechanical inspection capacity when the workload is high compared to the available resources, new labor resources should be easily applied in inspection. For other employees to adopt the mechanical inspection tasks, a comprehensive framework for inspection routines should be produced to enhance knowledge sharing.

Low level of employee empowerment

In the interviews, the inspectors indicated that they do not have influence on improving their work and tools. The inspectors wish that they could execute some of the small design tasks that are currently ordered from the mechanical design team, because of the waste caused by ordering mechanical design work as described earlier in this section.

Manual work that could be automated

There is a significant amount of manual work in inspecting the BOM. Due to observation, the author was able to identify tasks that could be automated by implementing an Excel inspection tool. The tool is introduced later in Chapter 4.2.3.

There are cases, where the product configurator does not generate any mechanical components to the part list, and thus the inspection work requires significantly more time as all of the components need to be figured out from the scratch. In addition, some features have not been integrated to the product generator. For example, the application engineered doors are not generated from the system, and hence they are changed manually to the BOM. If they were generated directly to the drawings, time and effort of the mechanical inspection would be saved.

Mistakes in upstream functions

The lack of knowledge or disregarding the general mechanical guidelines in upstream processes can cause unnecessary work for the inspectors. For example, it is a common rule that the lineup should never end to an empty cabinet unit but to a junction unit. Despite the rule, sometimes the order is confirmed so that empty unit is at the end of the lineup. This, again, requires additional manual work of the inspectors to switch the empty unit to a junction unit. As the amount of manual work increases, the risk of errors and mistakes increases.

There is no clear overproduction identified in mechanical inspection. The problem lies in other processes. For example, the project engineers might hurry their work in the work queue even though there are more critical orders in the work queue. Thus, if the prioritization of the orders is not correct, work might be done earlier than required and as it leaves the current process, it stays in queue in the following process, like project engineering, and is not released to production immediately, for example.

Excess components in BOMs

Inspection defects emerge in production as faulty, missing or unnecessary components. If inspectors are uncertain of a component, they choose to add unnecessary components as it has the least negative effect in production. The quality engineer of the production confirmed that there are commonly more components than required. For example, there are both a standard part and an application engineered part in the BOM, as the application engineered part is added to the BOM but the standard one has not been deleted.

Defining door cut-outs incorrectly

A common defect is that the door cut-outs are defined incorrectly, which already arose in the Kaizen workshop. The inspectors spend time defining the places for the door cut-outs, and if they are not correct, the time spent is non-value adding. The work is then redone in the production.

Delays due to high workload

As stated earlier in Chapter 2.2.3, defects can be additionally considered as delays in the process output. Delays in mechanical inspection are due to high workload or unexpected issues. Unexpected issues can cause additional work with finding information or require mechanical design. If the mechanical design does not finish before the due date of the project due date, there are two options to consider. The project can be released in to production as soon as the design is ready, but without mechanical inspection. This enables the timely production start but can cause problems in production due faulty or missing components. If the inspection work is done, the defects are minimized but the production start is delayed.

Contradictions between the manufacturing drawing and other documentation

Another topic concerning the manufacturing drawings occurred. Occasionally, there are contradictions between the information in the manufacturing drawing and other documentation. Inconsistency in the documentation can reveal errors that would not be revealed otherwise. However, handling multiple documents that contain same information, can increase the probability of making mistakes. The mistakes cause confusion in the production area and clearance of the issues takes additional time in the production. Despite the issues, it can be considered that the mechanical inspectors create value by adding information to the manufacturing drawing, because mostly it speeds up the work at the factory floor. The contradictions do not occur often, and their negative effect cannot be seen significant compared to the overall value in the use manufacturing drawing in production.

4.2.3 Excel inspection tool

During observation, the author identified that some of the manual work in mechanical inspection could be reduced with automatization. The functionality of a possible tool is explained in Figure 14. At this point, it was examined if developing the tool is possible. The tool would be able to make the comparison between the components mentioned in the assembly drawing and the components found in the project BOM.

First, the assembly drawing to be utilized is assigned for the tool which converts the data from pdf to Excel. The initial data contains a lot of additional information from the pdf document, which is eliminated by using a set of conditions. The goal is to obtain a list with only material codes. The type of the material should be defined, meaning if it is a component or another assembly drawing. In addition, the condition defining the use of the material is connected to the material code. It is necessary for the next step, where the user gives project-specific conditions. The second list consists only of materials that contain the same conditions as the conditions given by the user. Then, if the list includes other assembly drawings, another iteration begins, and it fetches similar information from the other assembly drawings as well.

The final list should contain all the components defined in the assembly drawing for the given conditions. In order to give the output of the tool, the list of missing components in the ERP BOM, the tool compares the Excel list to the BOM. Then, the inspector can manually add the missing components to the ERP BOM.

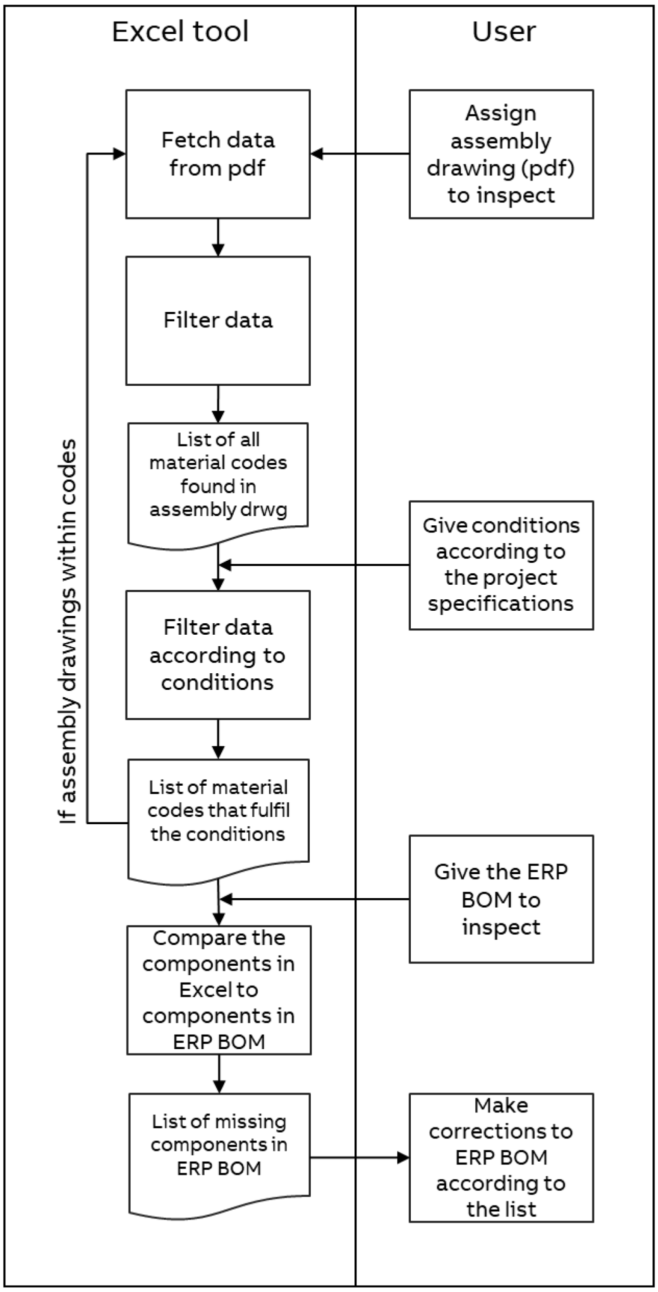

Figure 14. The operating principle of the Excel inspection tool.

4.3 Findings from the work time analysis

The findings from the data analysis of work time were unexpected but valuable. The data analysis did not proceed according to the initial plan. The results emerged already in the data organization phase, where the data was processed in the correct form to conduct analyzes. The major finding was that there is not enough valid data that could be analyzed in order to make any conclusions about the performance of the process.

It was found that in mechanical inspection, only for 7 % of the projects over a year had hours recorded in the ERP system. The respective number for mechanical design is 22 %. As the number of applicable samples is very small to describe the situation in real life, approaches for both mechanical inspection and design were applied in order to grow the number of the samples. The approaches are described in the following sections.

4.3.1 Mechanical inspection data

To tackle the issue of missing work hours for majority of the projects, the finishing and starting dates for the projects were decided to be used. The finishing and starting dates were recorded in the system for 43 % of the projects, which could give a more accurate description about the situation in real life.

First, it was evaluated how the dates could be converted to accurate work hours. It was done by comparing the dates to recorded hours of the 7 % of projects that had hours recorded. To convert the dates to hours, it was assumed that in one working day a certain number of hours was utilized for the project. Three, four and six hours was tested in the conversion in order to find the most accurate conversion approach. Weekends and national holidays were subtracted from the dates that were converted to work hours. However, in some cases the inspectors have worked over the weekend or national holidays, and there was no efficient way to figure out which projects have been proceeded during weekends or holidays, and by how many days. For example, a project had been started on Saturday but finished on Tuesday. The dates do not indicate whether the work has been done on Sunday as well.

After transforming the dates to hours, the three resulting work hour sets for each project were compared to the actual recorded hours, which is shown in Figure 15. The grey line in the graph represents the recorded hours. Blue line is for the approximated hours based on the assumption that one day is respective to three working hours. Respectively, the green line is for the 4-hour assumption and yellow for 6-hour assumption.

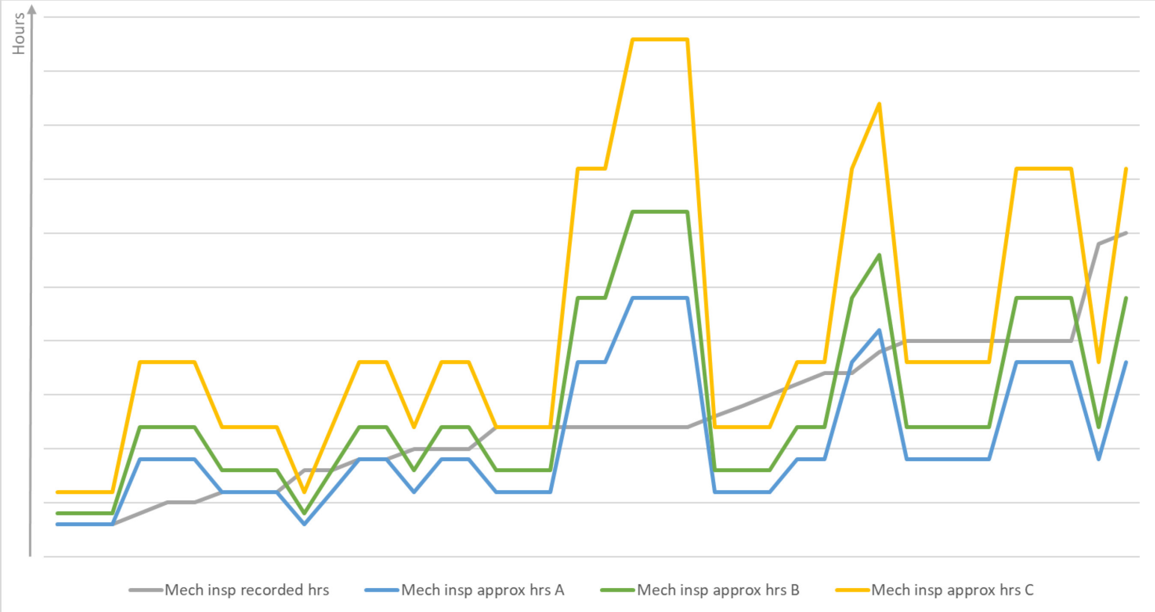

Figure 15. Recorded and approximated inspection hours illustrated. X-axis represents the projects, and the Y-axis the number of hours. The grey line graphs the hours recorded in ERP for each project, and the other lines represent the approximated hours based on the assumption of certain daily hour number for the respective project.

The graphs indicate that the date approximation technique does not give accurate data. Table 5 shows a summary of the difference between recorded hours and approximated hours. The variation in the approximated samples is high. The approximated values do not correlate with recorded values to the extent that the approximated values would describe the recorded values. The difference in hours is significant, and even at the best (the 3-hour assumption), only for 40 % of the projects the difference is up to two hours and for 30 % it is more than 8 hours. The mean value for recorded hours is 13 hours and the standard deviation is less than 7 hours, and therefore an 8-hour difference, for example, creates an enormous distortion to the data, and is thus, inapplicable to describe the real-life situation.

As no further analysis is possible to conduct with the available data, the result of the work time study on the behalf of mechanical inspection is to recommend recording the work hours to ERP systematically and conscientiously.

Table 5. A summary of the difference between the recorded hours and the approximated hours.

	Approximated hours with the value of 3h	Approximated hours with the value of 4h	Approximated hours with the value of 6h
Average difference (h)	-2	1	8
Max difference (h)	12	20	36
Min difference (h)	-20	-17	-11
Samples that have only 0-2 h difference	40 %	25 %	33 %
Samples that have more than 8 h difference	30 %	30 %	45 %

4.3.2 Mechanical design data

With mechanical design team, the case was somewhat similar to the inspection team. As only 22 % of the projects had recorded hours in ERP, more data was fetched from the work queue Excel in which the hours were recorded as well. The first step was to confirm that the data in ERP and in Excel were equal for the projects that had hours recorded in both. Surprisingly, however, the hours in ERP and Excel were divergent, which is illustrated in Figure 16 and Figure 17. Blue lines, dots and bars in both figures represent hours recorded in ERP and orange ones represent the Excel hours. Figure 16 shows that there is no correlation between the data from ERP and Excel.

The graphs and Table 6 show that there are major discrepancies between the hours. Although the data sets should be exactly equal, more than 70 % of them are divergent, and only third of the data has up to two hours difference. 52 % of the projects have more than an 8-hour difference between the two systems. The largest difference is up to 47 hours, which represents more than a full working week.

It can be stated, that the ERP and Excel hours cannot be compared. In addition, it is unknown, which one of the systems have accurate hours for the analysis. Therefore, the key finding for mechanical design is to pay attention to the recording of work hours both in Excel and in ERP.

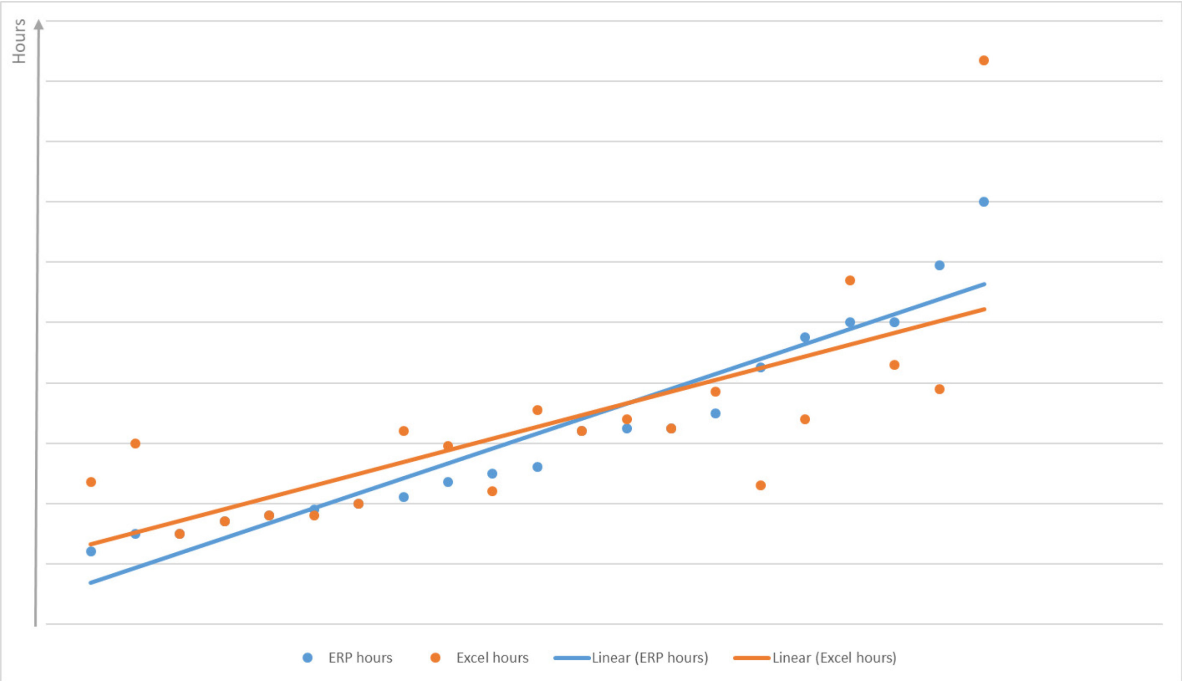

Figure 16. Recorded SAP hours compared to work queue Excel hours. The X-axis represents projects, and the Y-axis represents the number of hours. The data points of ERP hours and Excel hours are unequal, and the linear representations of the data points do not correlate.

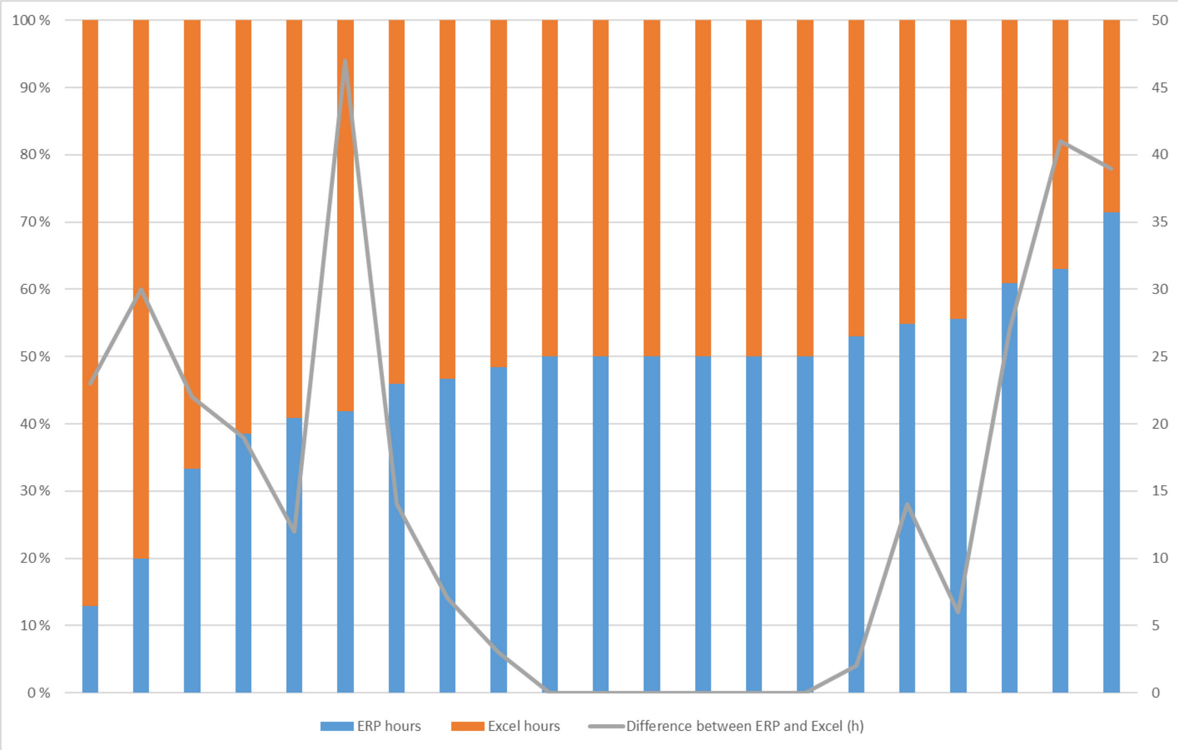

Figure 17. Difference between hours recorded in ERP and in Excel. X-axis represents the projects. The grey line represents the difference in hours as positive integers for each project. The bars represent the difference in percentages where the blue part is for ERP hours and the orange part for the Excel hours.

Table 6. Average, maximum and minimum values of the recorded hours in ERP and in Excel.

	ERP hours	Excel hours
Average (h)	43	45
Max (h)	120	167
Min (h)	4	10

5 Discussion

The present study evolved during execution, which is typical for qualitative research (Bell & Waters 2014; Denscombe 2009, p. 109). As the research proceeded, many issues emerged, and new approaches had to be considered. As discussed in Chapter 2.1, KIBPs are difficult to describe and analyze, which occurred at the present study for the part of data collection of mechanical inspection.

First, the Kaizen workshop was organized, and it was a kick-off event for the project. The workshop gave several practical improvement targets for mechanical design, and the event in this respect was a success. For mechanical inspection, however, the workshop did not work as well as expected. Therefore, it was decided to put the attention to the mechanical inspection and apply other methods to study the inspection process as the improvement project for the inspection seemed more complex than for the design team.

Next, one of the inspectors was interviewed in order to dig deeper into the mechanical inspection process. No significant findings emerged. It was considered, that the best possible way to get really acquainted to the inspection process was for the author to learn the process through participant observation and apprenticing.

The results of the present study act as a valuable information for understanding the mechanical inspection process. Process was described thoroughly, and the value added analysis was conducted, which provided identification of weak points in the process. Process description can be utilized to provide information for different departments within the company to understand the OSE mechanical inspection process. Based on the results, the company can evaluate how to redesign the process and what should be taken into account in the decision making of the possible changes. In this chapter, the results are discussed and analyzed in the case company perspective, and recommendations for improvement are given. In addition, this chapter evaluates the research validity and reliability, and the significance of the study in a general context.

5.1 Research validity and reliability

According to Denscombe (2009, pp. 144, 150-151) research methods can be considered reliable, when the findings are similar in different settings, by different researchers, at different times or with separate groups of similar people. Qualitative research methods, like questionnaires, workshops and observations, usually tackle with the reliability of data collection. Denscombe (2009, p. 152) and Rantanen & Toikko (2009) suggest that some precaution to the research results should be taken and the validity and reliability should be objectively analyzed.

For example, if the workshop had been organized at some other day by another Kaizen leader, most probably the results would have been different. However, if we look at the qualitative research methods, like the workshop, from a different perspective, they can be considered reliable despite the difference in concrete outcomes with different research settings. Regardless of the time, the people or the leader of the workshop, the workshop produces results from the team's point-of-view and creates an opportunity for the team members to participate and have an influence on the development. Instead of being exclusively a data collection method, the workshop is a tool that enhances the application of the continuous improvement culture.

Denscombe (2009, pp. 143-144) states that even though the quality of data is usually associated to validity and that the validity is an important issue in research, it is not extremely vital in qualitative research. In the Kaizen workshop, the results are based on intuitive decisions in both pain-frequency prioritization matrix and benefit-effort matrix. They were not analyzed with statistical, reliable methods. However, as they resulted directly from how the employees themselves experience the situation and their work, the realization of the suggested improvements can be seen beneficial. It builds trust to the management, when the employees perceive that their opinions are listened to.

In general, Kaizen leader should be experienced to achieve best results (Bradley & Willett 2004). However, the author decided to lead the workshop by herself with only a little experience of the Kaizen method. In the research of Farris et al. (2009) it was found that even though unexperienced Kaizen leader can affect negatively to the workshop capabilities, the impact on the motivation and attitude of the participants is positive. Therefore, even if the choice of leader was the cause of failing for the part of mechanical inspection in the Kaizen workshop, it might have resulted in increased motivation and attitude among the inspectors and assisted the success of following research methods.

The consistency and neutrality of research tools like observation and interviews is difficult to achieve. The presence of observer or interviewer easily affects to the results. (Denscombe 2009, p. 152; Dumas et al. 2013, p. 162) The author attempted to maintain an objective view as an interviewer and as a participant and exclude her subjective thoughts about the subjects, so that the outcomes would be as neutral as possible. Eventually, the issues arisen during the workshop, interviews and observation were similar to the issues introduced in Chapters 2.1 and 2.3. Thus, the results can be considered valid as they represent the generic problems within ETO processes described in the earlier studies.

Regarding the worktime study, it can be considered that the validity and reliability of the data was taken well into account. The data was analyzed from the very beginning in a way that excludes the major issues concerning data validity. As the outcome showed that the data was entered into the system in inconsistently, it was conducted that the quality of the data is insufficient for analysis.

5.2 Conclusions and recommendations

Based on the results and the value added analysis, a set of recommendations were concluded for the case company. The topics are presented in Figure 18.

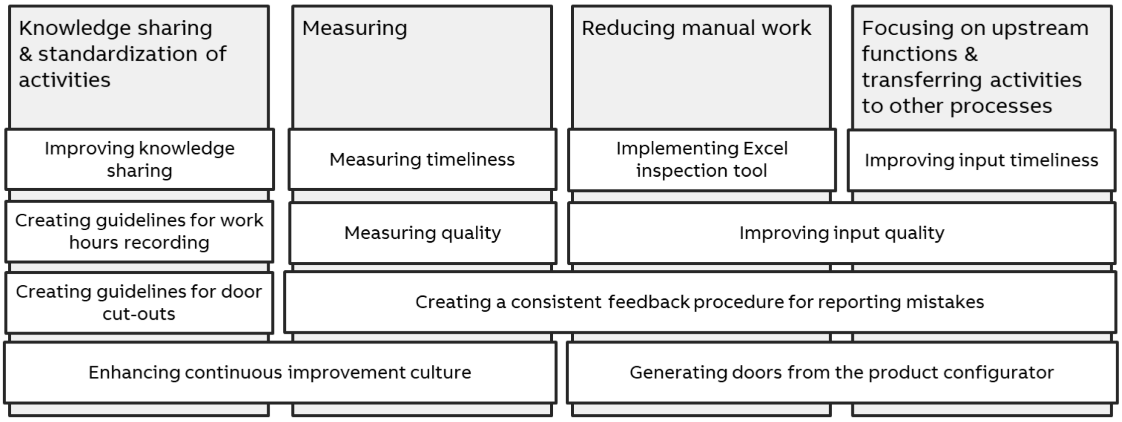

Figure 18. The topics of recommended actions for the case company.

Knowledge sharing and standardization of activities

The continuous improvement culture should be reinforced in the mechanical engineering team. It could be seen that as the present study evolved, the attitude of the mechanical inspection team transformed in to more cooperative, and enthusiasm towards process improvement increased. The management should make sure that the gained benefit in the employee participation does not fade after the study.

In the mechanical inspection, the work is executed in a way that the employees have adopted over years. During observation, the inspectors showed vast interest in new ideas presented to them and recognized the aid that new solutions could provide in their work. However, their creativity to produce ideas by themselves seemed limited. The employees should constantly review their working habits and share their knowledge among others. They should be encouraged to think about different ways of completing the tasks and using the current tools. They should be introduced to new tools that could improve their way of thinking or be applied in their daily work. For instance, an Excel tool that forms a list of components to be painted was developed approximately a year before one of the inspectors used it for the first time. The inspector found the tool highly advantageous. It is important to make sure that the employees adopt new tools and ideas when they are introduced in order to facilitate the daily work. It is difficult for the employees to understand the benefit of improvement actions if they do not adopt the solutions they are provided.

A major subject concerning the issues presented in Chapter 4.2 are related to the difficulty of finding knowledge from previous projects. Most of the information is person-dependent, meaning that the information retrieval is mainly based on relying on the memory and personal files of few individuals. If a key person for a certain case is unavailable at the moment, another person needs to spend a great amount of effort and time to find the correct information as he does not have relevant information or remembrance of a specific reference project, for example. Therefore, the knowledge database should be improved, and its use should be reinforced in order to keep it updated and advantageous. Employees' personal archives should be combined so that everyone has access to relevant information whenever required.

Work time analysis uncovered the lack of recorded working hours, as described in Chapter 4.3. Attention should be paid in both mechanical inspection and design so that the work hours are recorded consistently. Accurate work hours are important as they are valuable information when running final cost calculations to the projects and create an opportunity for future work time study and measurements. A common practice for recording hours should be created and followed. As product lineups can be to some extent copies of each other within the same sales order, it should be decided how the hours are divided among the lineups. For example, the inspector might spend a great amount of time when doing the first lineup and finding out information related to it, and only copies the work to the second lineup. Thus, it should be decided if the actual work hours with the first lineup are divided among the two lineups, or if the first lineup has the actual work hours and the second one only the time spent copying which is only a fraction of the actual work hours.

A general guideline for defining the door cut-outs should be specified. The issue is substantial, and it came up already at the workshop and recurred in the observation and interviews. At the moment, there is a person in production who is responsible for creating the door cut-outs. He has the most knowledge of the topic in practice, and he should be consulted in order to create a guideline for the door cut-outs. In addition, it should be considered who has the actual responsibility of defining the door cut-outs.

Measuring

Mechanical inspection process is not currently measured by any means. As discussed in Chapter 2.2.2, performance metrics give important feedback about processes. Throughput time can be measured by applying a similar data analysis approach as described in Chapter 3.4, if the work time data is accurate.

For mechanical design, quality could be simply measured with the number of defects found in downstream functions, like inspection or production. However, for mechanical inspection the definition of quality metrics is challenging. The feedback usually goes to product development or product engineering, who make the changes in the system and the changes are generated to future inspection projects. It cannot be easily defined which of the errors are due to product development and which are due to the inspection.

In addition, quality of other functions could be measured if mechanical inspection gave feedback through an official engineering change management system. At the moment, they only use unformal channels to give feedback about the mistakes, which does not leave a mark in the system, and thus, the quality from that part cannot be measured. Using change management system would provide visibility in how much correction work the inspectors execute, and what is their significance in the organization. However, the employees do not feel comfortable using a change management system and prefer unformal channels. The employees could be engaged to reporting defects by, first, simplifying the reporting procedure and giving the responsibility to a dedicated person. Then, the effect of reporting could be presented to them with a report that describes the effect in figures, which would most probably show the significance of the given feedback, and thus, the employees would be more willing to adopt consistent reporting of defects.

The timeliness of the inspection and design can be measured with how they meet with the estimated finishing date. This, however, might cause the phenomena of releasing the work before it is finished and correcting it afterwards. This, again, leads to project management difficulties. The production is not provided with correct documentation, which increases the number of changes required during production, and can lead to delays in the final product delivery.

Reducing manual work in inspection

As mentioned in Chapter 2.2.3, tasks that are completed by skilled employees but do not require knowledge, should be automatized. Thus, resources would be available for executing value adding knowledge-intensive activities.

The implementation of Excel inspection tool, introduced in Chapter 4.2.3, is a concrete way of reducing manual work that does not require knowledge in inspection. If the implementation is successful, it can provide a significant assistance for the inspectors. Especially in projects that contain a high number of components, the tool could speed up the inspection process substantially. In addition, the tool would enable transferring the inspection to other functions, like project engineering. At the current state, the knowledge and experience of the inspectors enables executing the inspection process at high speed because they know which units and components require special attention. For less experienced employees similar case would be much more time consuming, as they should go through the whole BOM in order to be sure that everything is in order.

However, it should be considered if the resources spent developing, implementing and maintaining the tool is cost-effective. As the mechanical inspection acts as a function that corrects the mistakes in upstream functions, the tool serves only as a solution to the problem occurring at the mechanical inspection but does not solve the root cause.

To avoid duplication in work, the inspectors should give feedback about the defects noticed in the drawings and bill-of-materials. If the errors are not reported, they will appear again, and the inspectors need to manually correct them time after time. At the current state, the inspectors report only some of the mistakes, usually for projects that contain a vast number of errors. There are both product development and product engineering departments, that are responsible of correcting the mistakes, and it is usually not evident which department is responsible of each case. The inspectors feel that the reporting is burdensome because they already have high workload with other tasks, and if there is no clear procedure in giving the feedback, it is easily left undone. Thus, a clear reporting procedure should be defined.

For most of the BOMs, doors are generated incorrectly. The product configurator does not include application engineered doors, so they need to be changed numerous times. As the mechanical inspection should act as an inspection function rather than a design function, the BOMs should be primarily generated from the configurator correctly. The capacity and performance of mechanical inspection highly depends on upstream functions. Therefore, endeavor should be put into the product configurator so that it would generate correct doors. In addition, to reduce the effort in defining door cut-outs, modular structure for doors could be considered.

Focusing on upstream functions and transferring tasks to other processes

In order to reduce the risk of mechanical inspection being the bottleneck in the ETO process, not only should the inspection itself be investigated but the upstream processes as well. The reason the inspection as a function exists is that the inputs to the ETO production are of low quality, and they need to be inspected to avoid problems in the production phase. The inspection acts as a function that conceals issues in a larger context.

The workload varies in the mechanical inspection. It is due to the uncertainty in the ETO process. In ideal situations, where unexpected events do not emerge, it is possible to divide the mechanical inspection work evenly if the capacity of mechanical inspection is considered in the calculations when the delivery time is confirmed and the time schedule is planned. However, the projects do not always proceed according to the initial plan. For instance, occasionally the customers do not approve the preliminary dimension drawing according to the initial schedule. It immediately affects to the OSE and inspection workload. The inspection is started late, and if there are many delays in the input of the inspection process, the inspectors are first left without projects and after a while they face a workload spike. The spikes cause delays in the inspection process and, thus, late production starts. Spikes can be handled with overtime, but it increases costs and causes additional strain to the employees. In addition to the late customer approvals, other unexpected events like customer changes, design issues or urgent consultation might emerge, which disturb the planned resource utilization.

The quality of input in mechanical inspection varies, which causes uncertainty. Some of the projects entered in the mechanical inspection process are in fair state, meaning that initial specifications are well defined and there are no unexpected issues encountered during the inspection. However, some of the projects enter the process in raw state, and unforeseen issues emerge during the inspection which delays the work completion. Therefore, it should be defined, which is the ideal state that the inspection requires from the work orders, so that the project engineers could aim to the ideal state.

The faulty documents that require inspection are due to the configurator. If configurations are defective, the BOMs do not generate correctly. There are even cases when no mechanical components are generated to the part list. It requires a great effort to construct them from the scratch. Additionally, the lack of knowledge in upstream processes, like project engineering and sales, can cause additional correction work for the inspection as orders are confirmed with unrealizable mechanics. Thus, the upstream processes should aim to provide high-quality inputs for the mechanical inspection in order to avoid unexpected issues causing excess load in the inspection.

The significance of the inspection is the greatest with new products that have not been manufactured before. New products and their documentation contain a high number of errors, as they have not been finalized properly before the release. The inspectors play an important role in ensuring quality. They report the errors to product development and product engineering, which make the corrections and finally, after some years, the errors are in many respects eliminated of the most common products. Thus, the inspection acts as an enabler for the release of products with unfinished design. A major part of the workload of the mechanical inspection could be reduced by ensuring design quality already in the product development.

Nevertheless, as stated in Chapter 2.2.3, the impact of transferring tasks into other processes should be carefully examined. Although faulty configurations and mistakes in product development cause work in mechanical inspection, the resources required in ensuring quality do not change in the larger context. Quality assurance is required regardless at some point. Conducting the quality assurance already in the product development phase would be beneficial for the OSE process, as workload would be diminished from the inspection, and the resources would be available to tackle the uncertainty of ETO process. However, the product development department would require more resources in ensuring quality. In addition, the number of product variants is enormous, and therefore it is nearly impossible to test every single variant.

5.3 Significance of the study

The present study mainly serves the case company. The results describe the employee perspective in OSE process. The employee perspective can be generalized in to some extent. In addition, the significance of the present study in a general context concerns the applicability of different research methods and their use in the process improvement framework regarding describing and understanding processes in-depth. It gives information on how to gain knowledge about processes and how different data collection tools can be applied. The results describe the best practices and pitfalls for each research method applied in the study, that are valuable knowledge for future research in similar cases.

Even though the literature presented in Chapter 2.2.2 advises to take cautions when proceeding with observation as a research method, the outcomes of the present study show that observation was an efficient method both in data collection and in employee involvement and empowerment. The observational study resulted in similar benefits as the Gemba walk, introduced in Chapter 3.2.2, is claimed to produce. The author engaged in the daily work of the employees and spent time to understand their day-to-day work with curiosity and was able to gain the trust of the employees and a realistic perspective of the current situation. The employees responded with enthusiasm, when they were introduced to improvement ideas. Therefore, it can be claimed that the Gemba philosophy is applicable in the office in addition to manufacturing when it is executed out of curiosity and interest.

In cases where the processes are obscure in a detailed level because of lack of continuous improvement and employee turnover, the observation can be considered the best method of obtaining knowledge and understanding about the process. In cases where the employees show interest towards process improvement and are cooperative, a Kaizen workshop is an efficient way to gain a sufficient process description, weak points and solutions to issues in a short amount of time. However, workshops and interviews require a lot of eagerness from the participants and skills from the executor, and when employee motivation is low, the outcomes can be expected to be vague. In order to provoke and encourage the employees to continuous improvement of their own work, their work and processes need to be learned through intensive participant observation, where the discussion can take place in the real-life situations.

5.4 Suggestions for future research

Based on the findings of the present study, it is recommended to focus on the root causes of the issues emerged in the OSE mechanical inspection. The possibilities on how to improve the product configurations should be investigated in-depth. For instance, the company should investigate a solution for adding application engineered doors to configurator and designing a modular structure for the doors to address the issues with door cut-outs, so that often recurring manual work in inspection could be reduced.

Literature suggests solutions to capacity issues that only address to the symptoms rather than the root causes which is the uncertainty of the ETO processes. Spare capacity (Siong & Eng 2018), hiring and firing resources, overtime (Carvalho et al. 2016) and restricting inputs in the bottleneck process before there is free capacity (Hinckeldeyn et al. 2014) are common approaches to control engineering capacity. However, adjusting personnel number in ETO companies with short delivery times is inefficient, spare capacity is expensive, overtime adds stress to employees in long-term and restricting inputs to wait free capacity can cause delays in deliveries. In conclusion, further research should be conducted to create a framework for addressing the capacity planning in ETO systems by other means.

Employee engagement is commonly recommended in the literature in process improvement. Although many of the methods utilized in the present study, like Kaizen and Gemba, claim to improve employee engagement, their efficacy in different situations have not been clearly defined. Therefore, more research should be conducted to set the most applicable methods for varying cases.

6 Summary

The present study aimed to describe and analyze the mechanical OSE process in the case company. ETO processes are often difficult to describe because of their complex nature, and they are often poorly managed. They are increasingly important as customer requirements are more demanding and varying. As ETO processes are challenging by nature, effort should be put in continuous improvement so that the process difficulties could be minimized. The need for improvement in the case company was justified by the lack of previous improvement efforts as well as the importance of the mechanical inspection in the overall ETO process and the reduction of the employees in mechanical inspection.

Several data collection methods were applied to gather a comprehensive description about the processes. First, a Kaizen workshop was applied in order to obtain a high-level process description, engage employees in the process improvement and to produce improvement targets together with the mechanical engineering team. However, the mechanical inspection team struggled with defining their process and finding improvement targets, and thus, the focus was transferred from the overall mechanical engineering team to the inspection team.

Next, interviews were conducted for the inspection and for production. Production employees were interviewed about the manufacturing drawing and its necessity in order to identify the value of creating the manufacturing drawing as a part of the mechanical inspection tasks. The mechanical inspection interview did not deliver information in desired level of detail. Therefore, participant observation was applied. Based on observation, the author was able to create an in-depth process description and conduct a value added analysis, which acted as a basis for the recommendations for the case company.

In addition, a work time analysis was executed for mechanical engineering to help define metrics for the processes. Instead of finding ways to measure the processes, it was found that the existing data is insufficient for exploitation. Therefore, resulting recommendation is to focus on consistent work hour reporting.

The key findings are according to the characteristic issues for ETO processes presented in literature. The findings concern knowledge sharing, standardization of activities, automatization, improving upstream functions and transferring tasks to other processes. Furthermore, the present study demonstrated the difficulties in describing complex processes and employee engagement and prejudices, which were consistent with the previous knowledge described in the literature. The present study was able to provide a thorough analysis of the applicable approaches to deal with the challenges. Participant observation was discovered to be an efficient way to obtain approval of the employees towards process improvement and to provide a detailed process description and analysis.

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Appendices

Appendix 1. Interview questions. 1 page.

Appendix 1. Interview questions.

1. How much interruptions do you experience in your work? How many times is a project, for example, interrupted during the workday with other unrelated matters?
2. How much waste (double work, unnecessary work, work that could be automatized, waiting) do you feel that there is in your work?
3. How much burden do you feel at work in general?
4. How well do you feel that the communication contrives to different stakeholders (rest of the OSE team, production, sales, R&D)? Is communication effortless and is the correct person found easily?
5. Do you feel that you have sufficient tools in work? Do you feel that the tools are effortless to use?
6. Do you feel that all the information required to complete your work is easily available?
7. Do you feel that you can have an influence on developing your work tasks and tools?
8. How do you feel about the quality of your work? How do you feel that high load, haste, interruptions and other factors affect to the quality of your work?
9. Do you receive feedback about your work? What kind of feedback do you receive and what kind of feedback would you like to receive?